Nucleotide Degradation and Quality in Ordinary and Red Muscle of Iced and Frozen Swordfish (*Xiphias gladius*)[1]

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ABSTRACT

In iced dressed swordfish, inosine monophosphate, initially the predominant nucleotide (5.2 μmole/g), was dephosphorylated to inosine during 19 days storage. Hypoxanthine increased very slowly to about 1 μmole/g while quality (taste panel) showed no significant decrease to 15 days but was near borderline at 19 days. These changes occurred more slowly than in cod and related species. The sequence of nucleotide changes occurred much earlier in the red muscle. Rapid freezing and storage at −26 C for 4–5 months inhibited nucleotide enzymic activity, and quality remained unchanged. Slow freezing and storage for 1 week at −4 C significantly reduced quality to borderline or unacceptable levels, but only slightly affected the nucleotide degradation, indicating that other factors were responsible for the loss in quality. Dephosphorylation and hypoxanthine accumulation continued during further storage at −4 C. The levels of hypoxanthine reached during 19 days iced storage or 4–5 months frozen storage were not sufficiently high to impart bitter flavors, except possibly in the red muscle. A simple measure of inosine (+ hypoxanthine) may be useful as a quality test; a supplementary hypoxanthine test could be used to confirm spoilage.

INTRODUCTION

Studies of a number of commercially important species of fish have shown that the predominant nucleotide in resting muscle, ATP,[2] undergoes rapid enzymic dephosphorylation and deamination to IMP during the struggle associated with capture, or soon after death in fish where antemortem activity has been less intense (e.g. Jones and Murray, 1960; Saito and Arai, 1957). The accumulated IMP is then degraded more slowly post-mortem via inosine to hypoxanthine (Jones and Murray, 1962; Kassemsarn et al., 1963), and eventually to uric acid, as follows:

$$\text{IMP} \xrightarrow{5'\text{-nucleotidase}} \underset{+\ \text{IP}}{\text{Ino}} \xrightarrow[\text{(or phosphorylase)}]{\text{Riboside hydrolase}} \underset{+\ \text{Ribose (ribose phosphate)}}{\text{Hx}} \xrightarrow[\text{(possibly bacterial enzymes)}]{\text{Oxidation}} \text{Uric acid}$$

Depending upon several factors such as species of fish, postmortem holding temperature, and perhaps antemortem activity and physiological condition as well, this sequence of changes may have progressed

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[2]The following abbreviations are used: ATP, adenosine triphosphate; Hx, hypoxanthine; AMP, adenosine monophosphate; IP, inorganic phosphate; IMP, inosine monophosphate; TN, total adenosine and inosine compounds; Ino, inosine; IN, inosine compounds.

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appreciably well within the period of edibility and before the proliferation of spoilage bacteria. This led to attempts to correlate these nucleotide changes with storage time in ice, and eventually to the potential use of hypoxanthine content as an index of freshness or of quality in chill-stored fish (Jones et al., 1964; Spinelli et al., 1964; Jones, 1965a).

In recent years, the contribution of the major purine nucleotides, nucleosides, and bases to flavor of fish has received increasing emphasis (see Jones, 1961; Hashimoto, 1965). Japanese work (Kuninaka et al., 1964) led to the establishment of a patent for the use of IMP as a flavor accentuator in foods. Hypoxanthine, however, at the levels reached during the edible period of iced storage, is thought to impart a bitter flavor (Jones, 1961; 1965b), and has been suggested as contributing to the bitterness of frozen porbeagle flesh (Dyer et al., 1964). On the other hand, the association of bitter flavor with hypoxanthine has been questioned (Hashimoto, 1965). In this relation, Spinelli (1965) concluded that flavor alteration due to hypoxanthine in sole occurred only when bacterial counts exceeded 10^6 per gram.

Little or no information is presently available on the rate and extent of nucleotide decomposition and its possible association with undesirable flavors in several less common but commercially important east coast species, such as swordfish (*Xiphias gladius* L.). These are longlined extensively by Nova Scotian vessels during the spring and summer months. The fish are caught in waters where the surface temperature may reach 20 C, and may remain on deck for several hours at high ambient temperatures before dressing; they may be held up to 3 weeks in ice on the vessel before landing and marketing. We undertook a preliminary investigation of the changes in nucleotide composition, especially the rate of hypoxanthine formation, and in quality as assessed by taste panel, in swordfish handled as in commercial practice and held in ice for various periods. Since the enzymes involved are also active during frozen storage (Jones, 1965b), the extent of these changes was determined in slow- and fast-frozen steaks prepared from the iced fish, and during frozen storage at −4 and at −26 C, simulating poor and good conditions of freezing and frozen storage respectively. Flavors may be more pronounced in red muscle, and since nucleotide breakdown had been found to occur earlier in red than in ordinary muscle of rainbow trout (Saito et al., 1959), the red muscle was investigated as well.

EXPERIMENTAL

Five small dressed swordfish, weighing 66–101 lb, longlined off the southern tip of Georges Bank by a commercial vessel, were landed at Northwest Cove, N.S., on July 14, 1965. Four of the swordfish had been very well iced for 7 days on the vessel, and the remaining one for 3 days. The fish were immediately re-iced for transportation to the laboratory. The 3-day iced fish and one of the 7-day iced fish were sampled and cut into steaks on arrival; the other 3 fish were packed in ice at the laboratory for total icing times of 12, 15, and 19 days before sampling and processing.

From each fish, 20 cross-sectional steaks, about 2 cm thick, were cut consecutively, beginning just behind the head and ending at or slightly beyond the midsection. Two steaks, one from the anterior region and the other from the midsection, were sampled immediately, then placed in polyethylene bags on ice for taste panel assessment on the same or the following day. The remaining 18 steaks were sealed in individual polyethylene bags, and divided alternately into two groups. One group was fast-frozen in a horizontal plate freezer (Dole Freze-Cel; plate temperature −40 C) for 1 hr, then stored at −26 C. The other group (to hasten lowering of the muscle temperature) was placed in air at −26 C for 1.5 hr, at which time the surface was partially frozen, although the steaks were still flexible; the steaks were then transferred to a storage cabinet at −4 C.

For extraction and analysis, samples weighing 5–10 g were taken from the dorsal area of the ordinary muscle, and also from the deep-seated red muscle which comprises 3.7–4.5% of the edible portion of swordfish steaks. The muscle samples were homogenized immediately with 3% perchloric acid as described previously (Fraser et al., 1965), and the extracts adjusted to *p*H 6.5 with 30% KOH. Samples removed from the frozen steaks were not allowed to thaw before extraction.

The concentration of TN in the neutralized extracts was calculated from the absorption of appropriate extract dilutions at 251 mμ, the wavelength of the isobestic point for pure solutions of AMP and IMP, where $E^{1\text{ M},\,1\text{ cm}}_{p\text{H }7} = 12.8 \times 10^3$. The relative proportions of adenosine compounds and of inosine compounds were then calculated from the absorption at 260 mμ, where $E^{\text{AMP},\,1\text{ cm}}_{1\text{ M},\,p\text{H }7} = 15.8 \times 10^3$ and $E^{\text{IMP},\,1\text{ cm}}_{p\text{H }7,\,1\text{ M}} = 7.9 \times 10^3$ (J. R. Dingle, personal communication). Hx in the neutralized extracts was determined enzymically with xanthine oxidase (Worthington Biochemical Corp., Freehold, N.J.) according to Jones et al. (1964). This procedure also measures xanthine; however, only trace amounts of this compound were detected during advanced spoilage in various species examined (Kassemsarn et al., 1963). During the Hx determinations it was noted that the absorption at 290 mμ of extract "blanks", especially those of red muscle, increased with time in ice. If it is assumed that this increase arises from uric acid (λ_{max} = 290 mμ) as a result of the oxidation of Hx in the muscle, an arbitrary measure of the uric acid content of the muscle may be calculated, using $E^{290\text{ m}\mu}_{1\text{ M},\,1\text{ cm}} = 12.2 \times 10^3$ (Kalckar, 1947). Each extract was shaken with Dowex 1(Cl^-) (Jones and Murray, 1964) to separate nucleotides (chiefly IMP in these commercially caught species) from the nucleosides and bases (principally Ino and Hx (Kassemsarn et al., 1963)) which remain in solution. IMP was then determined as the difference in IN concentration before and after resin treatment. A rough measure of Ino content was determined as the difference between the contents of IN remaining in solution after shaking with Dowex and that of Hx in the unfractionated extract. The use of ultraviolet absorption data in this manner for calculation of Ino contents by difference may not be as satisfactory as more direct methods of estimation, since interfering ultraviolet-absorbing material may be present, especially in extracts of

red muscle (cf. Tomlinson et al., 1964). Comparison of Ino contents so calculated with those determined after chromatographic separation of the individual nucleosides and bases by the procedure of Jones (1960) yielded results which agreed within 10% for several ordinary muscle extracts examined; with red muscle extracts, however, Ino values obtained by difference were up to 30% lower than those determined chromatographically.

For taste-testing of iced swordfish and of the frozen steaks prepared therefrom, steaks were baked at 260 C and uniform-size portions of the dorsal muscle served immediately to a six–eight member panel. Unfortunately, insufficient red muscle was present for organoleptic assessment by the panel. Duplicate panels were run at each time interval; methods of scoring for texture and taste have been described previously (Dyer et al., 1964).

RESULTS

Nucleotide Catabolism

ICED

In the ordinary muscle, the high initial level of IMP in the 3-day fish, 5.2 μmole/g, indicative of dephosphorylation and deamination of ATP during the catching, killing, and preliminary storage on the vessel, was progressively dephosphorylated, with resulting increase in Ino concentration to a level of 5.6 μmole/g in the 19-day iced fish (Fig.1). Hx increased only slowly throughout the iced storage period, reaching a level of 1.2 μmole/g at 19 days. No significant differences were apparent between samples from the head and from the midsection.

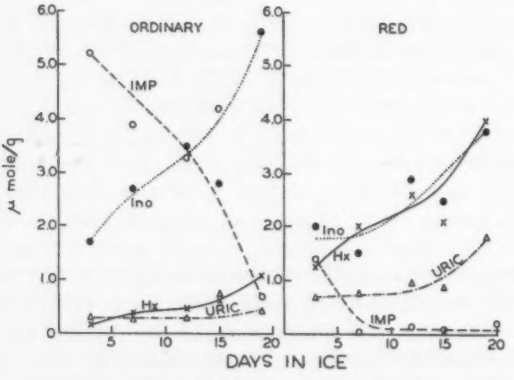

FIG. 1. Changes in IMP (○---○), Ino (●.....●), Hx (X———X), and uric acid (△ · – · – △) in ordinary and red muscle of dressed swordfish stored in ice. Each point (the average of two determinations) represents a different fish.

In the red muscle, the content of IMP (1.4 μmole/g) was at a much lower level than in the ordinary muscle at the initial 3-day sampling, and the content of Hx was at a higher level. Over the iced storage period, IMP disappeared quickly, and both Ino and Hx increased rapidly, reaching levels of 4 μmole/g at 19 days, indicating a rapid turnover of Ino to Hx, and that the sequence of nucleotide changes was considerably more advanced in the red muscle than in the ordinary muscle. These changes were in marked contrast to the ordinary muscle, where Ino accumulated with only a small formation of Hx. Uric acid had begun to appear in the red muscle of the 19-day fish, but not in the ordinary muscle.

FROZEN

In the fast-frozen steaks, no significant change (5% level) in contents of IMP,Ino, and Hx in the ordinary muscle occurred during freezing and frozen storage at −26 C for 4–5 months. This was also true for the red muscle, although results were more variable, and Ino was slightly lower in some frozen samples.

In both red and ordinary muscle of slow-frozen steaks, changes in levels of IMP, Ino, and Hx which had occurred to varying extents dependent upon iced storage time before freezing, continued to take place during storage at −4 C (Fig. 2). Small changes occurred in some samples during the initial freezing and 1 week's storage that preceded the first measurement. In the ordinary muscle, any IMP present at the time of freezing was degraded almost completely within 4 months, with concomitant increase in Ino concentration to levels of 4.8–5.9 μmole/g, as had occurred during iced storage of the dressed fish for 19 days (Fig. 1). The high Ino content of the 19-day muscle at the time of freezing underwent little change in 4 months at −4 C. In two of the four fish containing IMP at freezing, the rate of dephosphorylation of IMP to Ino was rapid during the freezing and 1 month's storage, whereas in the other two fish the rate was constant over the 4-month storage period. A steady increase in Hx concentration to levels of 2.0–2.5 μmole/g occurred in all samples of ordinary muscle over the 4-month storage period.

In the red muscle, IMP had practically disappeared by the time of freezing, so that the principal change during frozen storage at −4 C was a steady decrease in Ino to low levels at 4 months. In the frozen steaks from the 19-day fish, the decrease in Ino was rapid during freezing and/or the initial storage period. In all five fish, there was an accompanying rise in Hx levels of about 4 μmole/g at 4–5 months.

The content of TN in both ordinary and red muscle was not influenced by storage in ice for 19 days or by frozen storage at either −4 or at −26 C for up to 4–5 months. The level in the red muscle (6.1 μmole/g with S.E. of ±0.26 for 60 samples) was significantly lower ($P<0.05$) than that in the ordinary (8.2 μmole/g ± 0.13 for 60 samples), as was found for rainbow trout by Saito et al. (1959). Inosine compounds (IMP, Ino, and Hx in varying proportions) initially and throughout the storage period accounted for 88 (±0.7) and 71 (±2.9)% of the TN in the ordinary and in the red muscle respectively.

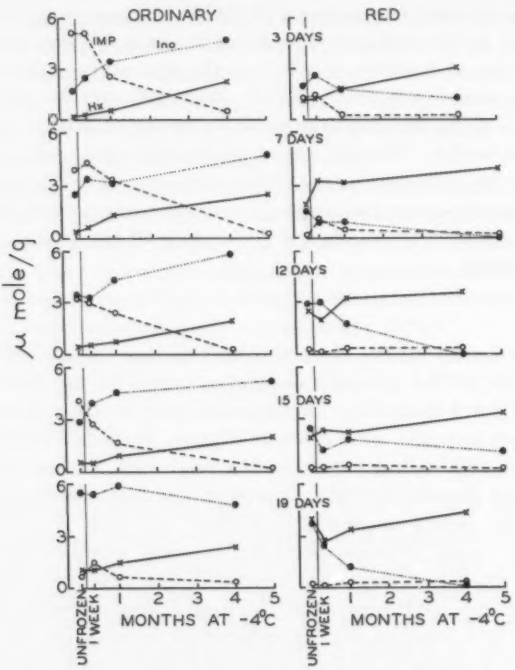

FIG. 2. Changes in IMP (○----○), Ino (●.....●), and Hx (X———X) in ordinary and red muscle of swordfish steaks slow-frozen and stored at −4 C. The steaks were processed from dressed fish held 3, 7, 12, 15, and 19 days in ice. Each point is the average of two determinations.

TASTE PANEL ASSESSMENT

ICED

The results (Fig. 3A) show no significant deterioration during storage up to 15 days in ice. In the fish iced for 19 days there was a drop ($P = 0.05$) in both taste and overall grade scores, and the quality level had reached borderline in the judgment of the panel. Some spoilage odors and flavors had appeared at this time. It was noted that even the freshest steaks had a quite acid, characteristic flavor which did not appeal to some panel members. This flavor was similar to that previously noted in porbeagle (Dyer et al., 1963). The rather large standard error was greater than normal (Dyer et al., 1964) and was probably attributable to insufficient familiarity of the panel members with this species. No significant difference was observed between steaks from the anterior and midsections of the fish (Fig. 3A); consequently, scores were combined both in calculating 95% confidence intervals and for the other figures.

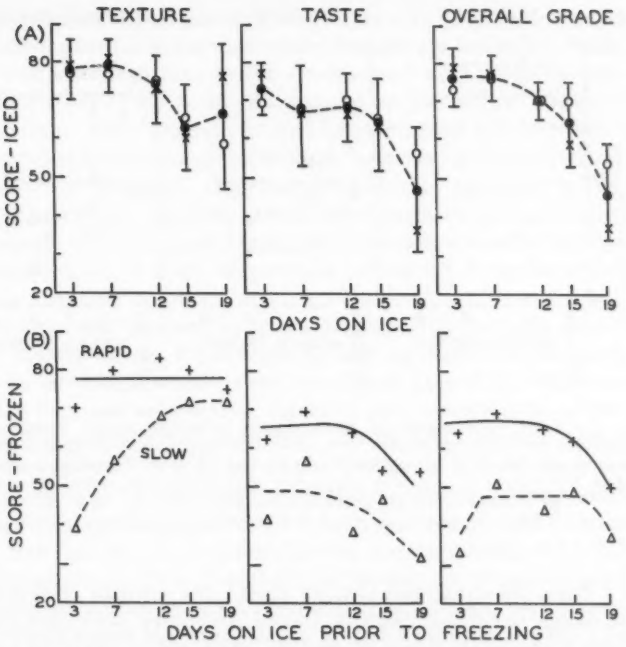

FIG. 3. Organoleptic assessment, texture, taste, and overall grade scores of cooked samples of dressed swordfish. (A) scores for steaks cut from the midsection (○) and anterior portion (X) of fish held 3–19 days on ice. Confidence limits (95%) of the means (combined scores from both sections) are indicated (n = 13–16); (B) scores for steaks of these fish both rapid-frozen (+) (plate freezer; stored for 1 week at −26 C) and slow-frozen (△) (still air at −26 C for 1.5 hr followed by storage at −4 C for 1 week). Each point is the average of combined scores for mid- and anterior sections (n = 11–12).

FROZEN

On freezing, the plate-frozen samples after 1 week at −26 C showed little change from the scores of the unfrozen fish (Fig. 3B). No further change was apparent on storage to 5 weeks (Fig. 4). In the latter figure, scores for frozen steaks from fish iced 3, 7, 12, and 15 days were combined, as these did not differ significantly.

On the other hand, the slow-frozen samples (−4C) showed appreciable deterioration, especially in taste and overall grade (Fig. 3B). This was so regardless of the time the dressed fish had been iced before freezing. Strong disagreeable flavors and odors described as sour, stale, and rancid had developed, and scores in the fish iced 3–15 days were reduced to close to borderline levels and to unacceptability in the 19-day fish. Texture scores in the slow-frozen steaks prepared from the 12-, 15-, and 19-day iced fish were unchanged from the unfrozen levels, but were considerably lower in the steaks from the fish

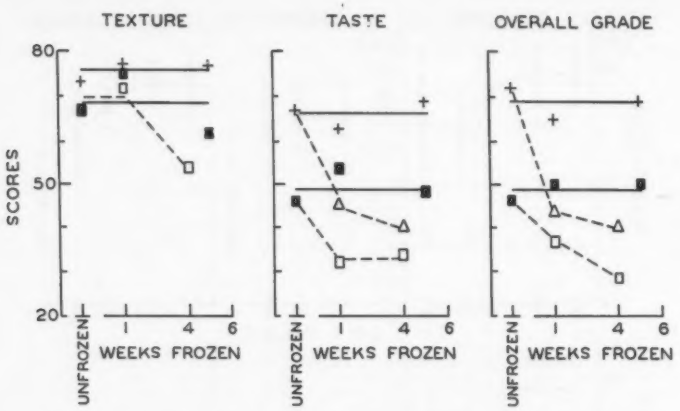

FIG. 4. Taste panel scores of stored frozen swordfish steaks (combined midsection and anterior steaks). + ——— + Average score of rapid frozen steaks stored at −26 C of fish iced 3, 7, 12, and 15 days. Tested at 1 week and at 4–5 weeks; △– – –△ as above but slow-frozen and stored at −4 C; ■ ——— ■ average score of rapid-frozen steaks stored at −26 C from fish iced 19 days; □ – – – □ as last, but slow-frozen and stored at −4 C.

iced 3 and 7 days. On continued storage at −4 C for 4 weeks (Fig. 4) a further decrease in scores occurred. Slightly putrid and very stale flavors became prevalent and some rubberiness of texture appeared. Growth of molds was evident in the samples at this time.

DISCUSSION

NUCLEOTIDE CATABOLISM

The high levels of IMP (5 μmole/g) measured initially in the ordinary muscle of swordfish were characteristic of values found for commercially trawled cod, haddock, lemon sole, and other species (Jones and Murray, 1960, 1962; Kassemsarn et al., 1963; Jones, 1965b). These high levels arose from the dephosphorylation and deamination of ATP during struggle in capture. The postmortem dephosphorylation of IMP during storage in ice took 19 days in swordfish (Fig. 1), and was therefore considerably slower than the 10 days observed in trawled iced cod, plaice, and coalfish (Jones, 1965b) or the 5–7 days in iced Pacific salmon (Creelman and Tomlinson, 1960). The corresponding rise in Ino had apparently not reached its maximum at 19 days, and thus was also slower than in the species cited above, where the maximum was reached within about 10 days. Similarly, the rate of Hx formation was not as rapid, reaching 1 μmole/g in 19 days, in contrast to maximum levels of 2–5 μmole/g reached in 10–16 days in iced plaice, cod, haddock, lemon sole, and coalfish (Jones, 1965b) and in English sole, petrale sole, and ocean perch (Spinelli et al., 1964). The slow rate of Hx formation in iced swordfish was similar to that reported for whole chilled halibut by Patashnik (1966), who measured

levels of approximately 2 μmole/g at 19 days. It therefore appears that the enzymes responsible for these nucleotide changes are less active in the ordinary muscle of iced swordfish than in the species cited above. It has been suggested that the formation of Hx from Ino may be augmented by bacterial enzymes, since the rate of Hx formation in gadoids increased considerably during the period of rapid proliferation of the spoilage bacteria, at 10–16 days (Kassemsarn et al., 1963). In swordfish, the observed delay in appreciable Hx formation would be in agreement with the greater time required for bacterial penetration into the muscle of these much larger fish. Spoilage was only becoming evident in the swordfish at 19 days, in contrast to the much earlier spoilage in cod (inedible at 15–16 days).

Stability of the prefreezing levels of IMP, Ino, and Hx was observed in swordfish muscle during rapid freezing and subsequent storage at −26 C. In contrast, in swordfish muscle slow-frozen and stored at −4 C the nucleotide degradative enzymes were active, resulting in a continuation of the changes in the nucleotide composition underway during iced storage; the rate of Hx formation was not influenced by initial quality as defined by storage time in ice before freezing. In agreement with these findings, Jones (1965b) reported that 5′-nucleotidase was inactive in frozen cod stored at −30 C, and nucleosidase at −20 C, but that all six enzymes effecting the degradation of ATP ultimately to Hx were active at −14 C. Similarly, no increase in Hx was observed in ocean perch stored 4 months at −29 C (Spinelli et al., 1964). Very little decrease in IMP level was found in frozen bonito stored 4 months at −20 C, but at −10 C levels decreased rapidly from 5 to 1 μmole/g (Sameshima, 1965).

Red muscle differed markedly from the ordinary muscle in the nucleotide degradative enzymic activity; the sequence of nucleotide breakdown was significantly more advanced in the red muscle (Fig. 1). IMP had completely disappeared in the red muscle after 7 days in ice compared with 19 days for the ordinary muscle. Considerable Hx was already present in the red muscle after 3 days in ice. These results indicate that the nucleotidase and nucleosidase responsible for these changes were active during capture and/or the preliminary 3-day storage period in ice on the vessel. During 15 days in ice the rate of Hx formation in red muscle was greater than in the ordinary, perhaps indicating a greater autolytic activity in the red. Between 15 and 19 days the apparent increase in activity in both red and ordinary muscle was indicative of augmentation by bacterial enzymes. The appearance of uric acid in the red muscle at this stage also may be due to bacterial action, and is in conformity with the advanced stage of the nucleotide breakdown sequence in this muscle. It should be noted that some xanthine may have been present in the Hx fraction. Uric acid, identified chromatographically, was found by Arai and Saito (1963) in larger quantity in the red lateral than in the dorsal muscle of both mackerel and mackerel pike, and was found to increase on frozen storage.

Our finding of an earlier nucleotide breakdown in red muscle is in agreement with results of Saito et al. (1959), whose data showed an earlier peaking and subsequent splitting of IMP to Ino and Hx in the red than in the dorsal

muscle of rainbow trout iced up to 3 days. At present, there appears to be no obvious explanation for this phenomenon. A parallel observation was the disappearance of acid-labile phosphate (derived chiefly from ATP) in 12 hr at 0 C in the red but not at all in the ordinary muscle of unexercised steelhead trout (Tomlinson et al., 1964).

Rapid freezing and storage at −26 C, but not slow freezing and storage at −4 C (Fig. 2), inhibited enzymic activity in the red as well as in the ordinary muscle. Although Hx levels were higher in the red muscle at the time of freezing, the rate of increase during storage at −4 C for 4–5 months appeared to be the same as in the ordinary muscle.

Quality Changes During Iced and Frozen Storage

The extended keeping quality of dressed swordfish up to 19 days in ice compared with a maximum of 12–14 days for cod and other whitefish (Reay and Shewan, 1949) may be attributed to the large size of the fish or possibly to the more acid *p*H of the flesh (*p*H 5.7–6.1). A similar extended keeping time occurs with halibut (Tarr, 1954). Bacterial penetration and diffusion of spoilage products into the flesh would be slower in the larger fish (Dyer et al., 1946; Ehrenberg and Shewan, 1955); bacterial growth is slower below *p*H 6 (Reay and Shewan, 1949), and the type of spoilage may also be affected, e.g. bacterial enzymic production of TMA is much slower below *p*H 6 (Castell and Snow, 1949).

Even though storage at −4 C might be expected to inhibit bacterial action, there was much deterioration in flavor scores in the steaks after 1 week at this temperature (Fig. 3B), whereas almost no change occurred in the iced fish up to 15 days (Fig. 3A). The deterioration was not related to prefreezing icing time, although texture scores of the 3- and 7-day iced swordfish were much lower on slow freezing. The results show that the unknown enzymic changes presumably responsible for the undesirable flavor development were more active on slow freezing followed by storage at −4 C than at ice temperature. The data, however, indicate that the enzymes responsible for nucleotide breakdown were not activated by the slow freezing process. It is well established that in frozen muscle many enzymes responsible for deteriorative changes have a very sharp peak in activity at temperatures just below the freezing point, approximately −2 to −4 C (see Lovern and Olley, 1962; Love and Elerian, 1964). In the freezing of very large carcasses, e.g. in air in shore plants or on fishing vessels, the time taken to pass through the temperature range −1 to −5 C may be appreciable. The present results indicate that serious quality deterioration had occurred within a week at this temperature; the minimum time required for a significant change in quality, however, remains to be determined. From a commercial standpoint, the results indicate that time in this temperature range should be minimized as much as possible to lessen the enzymic changes in nucleotide compounds and also the development of the disagreeable flavors which developed in swordfish steaks stored at this temperature for a week or less. It appears that these changes

are much more rapid in the dark meat, and this should probably be separated if a top quality product is desired.

Relation of Flavors to Nucleotide Catabolism

The taste panel did not detect any changes in flavor which could be related to the disappearance or the formation of any specific intermediate compound. The reason for this may have been the relative slowness of nucleotide breakdown in this species at ice temperature. It should be noted that any loss of fresh, meaty flavor caused by the disappearance of IMP, or the development of bitterness attributable to Hx, may have been masked by the rather strong characteristic sour flavor of the cooked swordfish steaks. It is doubtful, however, whether the levels of Hx reached during 19 days in ice, i.e. 1 μmole/g, or during frozen storage at −4 C for 1 month, 1.5 μmole/g, were sufficiently high to impart bitter flavors. The work of Jones (1961) and Jones et al. (1964) indicates that bitterness in whitefish species is associated with Hx levels of 2 μmole/g or greater. In the red muscle of swordfish, Hx levels were higher, and in species where the proportion of this muscle is greater or is eaten without being removed, bitterness may become apparent.

Usefulness of IMP and Hx as Quality Tests for Fresh and Frozen Swordfish

Since quality, as measured by taste and overall grade scores by the taste panel, changes very little up to the point where rapid spoilage occurs and then drops rapidly (Fig. 3A; Dyer et al., 1964), a correlation with an enzymic process where steady decomposition or accumulation occurs will not be linear. This appears to be the case with IMP dephosphorylation in the present experiment (Fig. 5). From this viewpoint, IMP levels do give an indication of iced storage time and consequently of remaining shelf life; very low levels suggest borderline quality. The same argument applies to Hx accumulation in the ordinary and in the red muscle. The relationship in the ordinary muscle between flavor score and Hx nevertheless appears to be nearly linear during the early part of the iced storage period, as was found for iced cod by Jones (1965a), although the levels in swordfish were lower for the same indicated score. To establish the usefulness of Hx and IMP as quality tests, it would be necessary to assess the variability by sampling many more fish under a range of commercial conditions.

As was proposed by Jones and Murray (1964) for cod, the present results with swordfish suggest that the simplest analytical test for measuring nucleotide degradation as a quality test would be the spectrophotometric measurement of ultraviolet absorption at 248 mμ on a perchloric acid extract treated with Dowex to remove nucleotides. This would give a measure of Ino plus any Hx present, and would increase during iced storage to a plateau at the point of onset of rapid spoilage; after this time a determination of Hx content by the xanthine oxidase procedure would confirm spoilage. Neither IMP nor Hx changed appreciably during slow freezing and storage at −4 C for 1 week and

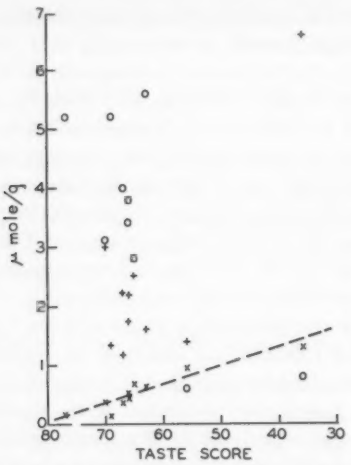

FIG. 5. Relation between taste score and IMP, Ino, and Hx in iced swordfish. ○, IMP in the ordinary muscle; X, Hx in the ordinary muscle; +, Hx in the red muscle.

thus measures of these compounds do not appear to be of value as tests for frozen quality deterioration since in this time there was a large decrease in organoleptic scores. However, these compounds may be used as indicators of prefreezing quality of frozen fish.

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Digestion of Fat by Cod[1]

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ABSTRACT

The gut contents of two cod were analysed for isomeric glycerides. Ten times more α,β-diglyceride than α,α'-diglyceride was found, and five to ten times more β-monoglyceride than α-monoglyceride.

A fat labelled with tritiated oleic acid in position 1 and with C-14-oleic acid in position 2 of L-glycerol was fed to two cod, and the diglycerides were then isolated from the gut content. Radioactive analyses showed them to be mixtures of the 1,2 and the 2,3 isomers.

In cod, therefore, dietary fat is degraded to diglycerides and monoglycerides by a digestive lipase which preferentially attacks the α-bound fatty acid esters but is not stereospecific. This enzyme corresponds in its action to the pancreatic lipase of mammals and of skate.

INTRODUCTION

A CONSIDERABLE PORTION of the marine biomass — and thus of marine diets — consists of fat. Animals ingest this fat, absorb it, and then either burn it or deposit it in their bodies for future use. Virtually nothing is known about the mechanism of this process in fish, but numerous studies have been made with mammals, and we may, for guidance, assume that fat metabolism in fish will not be very different from that in mammals. Restricting ourselves to the first stage, the digestion of fat, we know that in mammals the triglycerides are broken down by a digestive enzyme, pancreatic lipase, which specifically splits the fatty acid ester bonds in the outer or α-positions of glycerol. The result is a mixture consisting mainly of α,β-diglycerides, β-monoglycerides, and free fatty acids, and this mixture is absorbed by the intestinal wall. The mammalian pancreatic lipase has often been investigated, and much of our knowledge of fat digestion has been derived from *in vitro* studies with this enzyme. It stands to reason that a similar enzyme is produced by fish since it is unlikely that fish should be able to absorb intact triglycerides. The pancreas of a skate, *Raja radiata*, was indeed found to contain a high lipolytic activity which was α-specific, but not stereospecific, just like the mammalian enzyme (Brockerhoff and Hoyle, 1965); but it has not yet been possible to demonstrate such a lipase in a teleost fish. Reports in the literature on "lipases" of fish are usually found, on examination, to refer to the degradation of soluble esters rather than fats, or they list activities very much lower than that required of a digestive enzyme. Our own efforts to find the enzyme in the pyloric caeca or in the "diffuse pancreas" of cod, or in similar organs of various other fishes, have so

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far all been unsuccessful. Since it has not been possible to study the digestion of fat by fish *in vitro*, experiments *in vivo* were performed in the present study to see if triglycerides are digested in the same manner in teleosts as in skate and in mammals. First, the gut contents of cod, *Gadus morhua*, after a fatty meal were investigated; second, a doubly labelled triglyceride was fed to establish if the degradation of fat is stereospecific or not.

EXPERIMENTAL

Analysis of Digested Fat

A male cod, 46 cm long (cod I in Table I), was killed 30 hr after being fed with smelts, *Osmerus mordax*. This animal, as the following ones, had been kept on a diet of smelts and herring, *Harengus harengus*, for several weeks and then

Table I. Composition of lipid mixtures from the gut content of two cod, in mole per cent.

	Composition in mole per cent	
	Cod I (fed smelt)	Cod II (fed herring)
Triglyceride	19	30
Fatty acid	19	22
α,β-Diglyceride	8	18
α,α-Diglyceride	0.6	2
β-Monoglyceride	44	26
α-Monoglyceride	9	2

starved for 3 days before feeding. Three partly digested smelts were found in the stomach. The gut from the pyloric caeca to the anus was removed and cut into pieces, 5 cm long, from which the contents were squeezed out and left for 1 hr under 200 ml acetone, with occasional stirring. After filtration the acetone was evaporated to yield 286 mg of dry material, of which 145 mg were soluble in ether. These soluble lipids were separated by thin-layer chromatography.

Plates were prepared with silica gel G, with boric acid added to prevent migration of fatty acid on the partial glycerides (Yurkowski and Brockerhoff, 1966; Thomas et al., 1965). The solvent mixture ether–petroleum ether (b.p. 30–60 C, 40:60) was used to separate triglyceride, fatty acid, α,α'-diglyceride, and α,β-diglyceride (in this order of decreasing R_f values); the mixture acetone–chloroform (15:85) separated triglyceride, fatty acid plus diglycerides, β-monoglyceride, and α-monoglyceride, in this order (Thomas et al., 1965).

The lipids were located on the plates by spraying with dichlorofluorescein solution. They were then separately collected, eluted with chloroform–methanol (1:1), and converted to methyl esters – fatty acids by esterification with methanol–BF_3 (Metcalfe and Schmitz, 1961), the glycerides by transesterification with methanol–KOH (Brockerhoff, 1965). It was ascertained by thin-layer chromatography that the conversion was complete. The methyl esters were dissolved in CS_2, and aliquots were analyzed with a gas chromatograph supplied with a hydrogen flame detector. The recorded areas of response, measured by a disc integrator, were taken to be proportional to the amount of lipid applied; the areas obtained for triglycerides were then divided by 3, those for diglycerides by 2; in this manner, the composition in mole per cent of the lipid mixture was determined. Since the diglycerides and the monoglycerides had been recovered from different plates, the triglycerides recovered from both plates was used to correlate the concentrations.

A second cod, male, 53 cm (cod II in Table I), was fed with chopped herring and killed after 48 hr. Its stomach was found filled with partially digested pieces of herring. From its gut 459 mg of ether-soluble lipid was recovered and analyzed as described above.

Degradation of Stereospecifically Labelled Triglyceride

A triglyceride with different labels in the fatty acids 1 and 2[2] was prepared after the procedure of Hanahan and Brockerhoff (1960) Dioleoyl-9,10-H-3 lecithin was prepared from glyceryl phosphoryl choline (Brockerhoff and Yurkowski, 1965) and tritium-labelled oleoyl chloride. The β-fatty acid was then removed with phospholipase A (EC 3.1.1.4); the resulting lysolecithin was acylated with oleoyl-1-C-14 chloride; the doubly labelled lecithin was degraded to the diglyceride with phospholipase D (EC 3.1.4.3); the diglyceride was then acylated in position 3 with non-radioactive oleoyl chloride, and the resulting triglyceride was purified by chromatography on silicic acid and aluminum oxide. Radioactivity was measured with a scintillation counter. One milligram yielded 22,300 dpm for tritium, 18,100 dpm for carbon-14, the ratio H-3/C-14 being 1.23. According to the synthesis the triglyceride is a 1,2,3-trioleoyl-L-glycerol labelled with H-3 in oleic acid 1 and with C-14 in oleic acid 2. Since this method of synthesis has been successfully used in establishing the structure of lecithins (Tattrie, 1959; Hanahan et al., 1960) it is known that only little migration of acids on the glycerol can have occurred.

The triolein, 85 mg soaked up in a bread pill, was introduced into the stomach of a cod, male, 49 cm (cod A), and followed by a piece of herring. The animal was killed after 2 days, the lipids were recovered from the gut, the diglycerides were isolated by column chromatography and their activity was measured.

To a second fish, female, 43 cm (cod B), 70 mg triolein was administered. The fish was also killed after 2 days.

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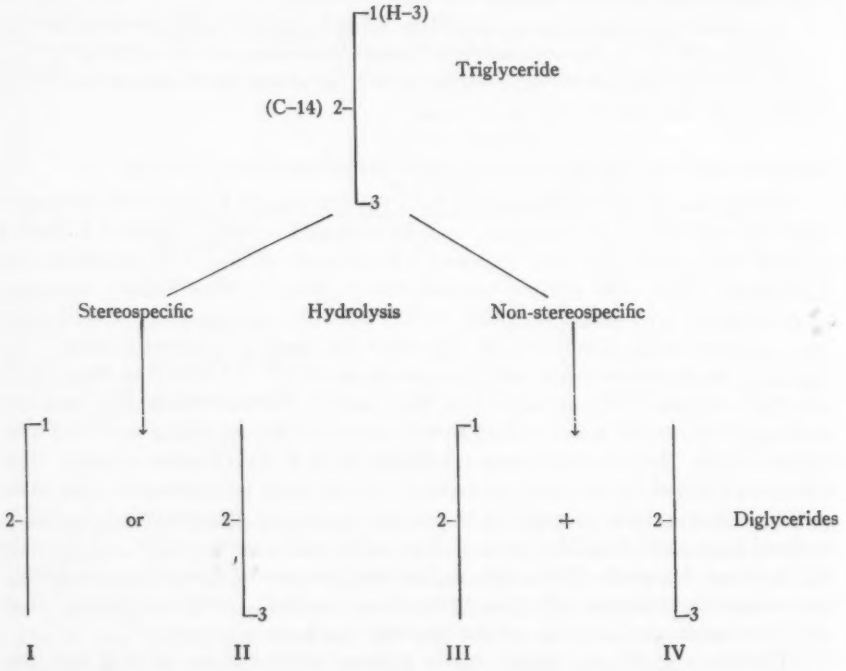
[2]1, 2, and 3 refer to these positions in 1,2,3-triacyl-L-glycerol.

RESULTS

Table I shows the compositions of the lipid mixtures from the guts of two cod, in mole per cent of the total lipid. The results important for our investigation are the relative proportions of the isomeric diglycerides and monoglycerides: there is ten times more α,β-diglyceride than α,α'-diglyceride, and five to ten times more β-monoglyceride than α-monoglyceride. It is therefore obvious that the triglycerides have been digested by an enzyme which preferentially attacks the α-ester bonds in the manner of the pancreatic lipases of skate and of mammals.

In order to test whether this enzyme is stereospecific a doubly labelled triglyceride was fed, and the ratio of labels in the diglyceride fraction of the gut lipids was determined. The following diagram explains this procedure:



The triglyceride contained oleic acid – H-3 in position 1, oleic acid – C-14 in 2, and unlabelled oleic acid in 3. The ratio of activities 1:2 was 1.23. Stereospecific removal of fatty acid 3 would lead to diglyceride I with the same ratio of activities; removal of acid 1 would yield diglyceride II with C-14-radioactivity only. Non-stereospecific lipolysis in position 1 as well as 3 will lead to a mixture of diglycerides III and IV; the ratio H-3/C-14 should be 50% of that of the starting material, or 0.62.

The diglyceride from the gut of cod A weighed 82 mg and had 19,900 dpm of H-3 and 31,000 dpm of C-14, that is a ratio H-3/C-14 of 0.64 or 52% of that of the triglyceride. Cod B yielded 49 mg of diglyceride, 29,000 dpm of H-3, 42,000 dpm of C-14, the ratio being 0.69 or 56% of the starting ratio.

The digestive breakdown of triglycerides is therefore non-stereospecific in cod just as in skate and in mammals.

DISCUSSION

The experiments reported here prove that in the intestinal tract of cod the dietary fat is largely digested to diglycerides, monoglycerides, and fatty acids; that the digestive enzyme is specific for the α-positions of triglycerides; and that this enzyme displays no stereospecificity towards glycerides.

Quantitative conclusions concerning the digestion of fat in cod cannot be drawn from the present data because of the nature of the *in vivo* experiments with their many uncontrolled and unknown factors. There are many aspects for future study by physiologists: the course of digestion in time and its dependence on the size and the nutritional state of the fish, on quality and quantity of the meal, on the temperature, and so on. The *p*H of digestion and other requirements also remain to be determined. Most interesting will be the search for the source of the "pancreatic lipase" of teleosts. It is quite possible that the "diffuse pancreatic tissue" does contain the enzyme and that only the right conditions have not been found to demonstrate its activity. During this study I tested the residue left after the extraction of the gut contents with acetone but failed to find any activity. Since the enzyme would be expected to accompany the products whose breakdown it catalyzes, the suspicion is strengthened that it may be active under conditions different from those suitable for the pancreatic lipases of mammals of skate.

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The Ultrastructure of the Epithelial Border of the Ileum, Pyloric Caeca, and Rectum of the Cod, *Gadus morhua*[1]

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ABSTRACT

Electronmicrographs showed that the free border of the epithelial cells of the pyloric caeca, ileum, and rectum of the cod, *Gadus morhua*, is made up of microvilli. Elongated microorganisms aligned parallel to the microvilli and with one end fitting into the bases of the inter-microvillus spaces were frequently found in the rectum. Such organisms corresponded in position to peripheral interlacing filaments visible with the light microscope.

INTRODUCTION

Ciliated epithelial cells have been described in the intestine of some teleosts such as *Protopterus* (Coujard and Coujard-Champy, 1947) and *Syngnathus acus* (Andrew, 1959). Al-Hussaini (1949) has discussed the possible evolution from a border with interlacing fibers in *Pterois volitans* which is similar to the ciliated border of lower chordates, to a brush border in *Scarus sordidus*, and thence to a striated border of the tetrapod type in *Mulloides auriflamma*, *Atherina forskali*, and the cyprinids studied. Thesen (1890) described cilia in the pyloric caeca of *Gadus morhua*. Our light micrographs (Bishop and Odense, 1966) show a prominent border on the free surface of the epithelial cells of the pyloric caeca and ileum of the latter species, which could be made up of long microvilli or cilia. Long interlacing filaments similar to those found by Al-Hussaini (1949) in *Pterois volitans* are often present on the apices of folds between the gland openings in the rectum. Material was therefore studied in fresh squash preparations and with the electron microscope to determine the nature of the border.

MATERIALS AND METHODS

Squash preparations of living intestinal epithelial tissue of *Gadus morhua*, anaesthetized with tricaine methane sulphonate were studied with the light microscope. For study with the electron microscope, pieces of intestine were rapidly excised with a razor blade in a cold room at 4 C. Any intestinal contents were washed off with the fixative, which was 2% gluteraldehyde made up in a 0.05 M phosphate buffer at *p*H 7.3, with 1% calcium chloride added to a point just short of precipitation. The specimens were placed in the fixative and chopped with a razor blade into pieces 2–3 mm square. After 3–12 hr in the fixative, the tissues were washed in four half-hr changes of the 4 C phosphate

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buffer, then further cut up until no dimension was greater than 1 mm. Post-fixation was carried out in 2% osmium tetroxide in the phosphate buffer at 4 C. The tissues were briefly washed in distilled water, dehydrated in acetone, and embedded in Araldite. Gold and silver sections were cut from the blocks with an LKB ultramicrotome, double stained with a saturated solution of uranyl acetate in distilled water and Millonig's lead hydroxide, and studied and photographed with an Hitachi HS7S electron microscope.

RESULTS

A squash preparation of the ileum showed no ciliary motion, but in the rectum large numbers of microorganisms showing an helical motion were present. The movement of each organism was independent of that of neighbouring organisms, and although in general they were lined up along the free epithelial border, occasionally one detached itself and moved away from the border.

Electronmicrographs of the epithelial border of the pyloric caeca (Fig. 1), ileum (Figs. 2 and 3), and rectum (Figs. 4–7) show that microvilli, but no cilia, are present. The microvilli reach lengths on the crests of folds between the gland openings of 3.1 μ in the pyloric caeca, 1.8 μ in the ileum, and 2.3 μ in the rectum, which are rather longer than those quoted for some other animals such as 0.6 μ–2.2 μ in the hamster intestine (Overton, 1965) and 1.12 μ in the human jejunum (Brown, 1962). Fibrils can be seen attached to the outside of the microvilli, which may correspond to the mucopolysaccharide coat described by Ito (1965) for the cat. These fibrils are most clearly shown in Fig. 4, and are visible in the other figures. Longitudinal filaments in the microvilli are apparent in longitudinal and transverse section, and they extend into the apical part of the cell (Fig. 6).

Some sections of the rectum show large numbers of organisms aligned parallel to the microvilli, with one end embedded among the microvilli of the cell (Figs. 8, 9, and 10). Figure 8 is a light micrograph included for comparison with the electronmicrographs. The microorganisms have an inner plasma membrane and an outer cell wall, and the cytoplasm is granular, especially near the membrane. These features and the absence of fusion of the cytoplasm of the organisms and the epithelial cells show that they cannot be extensions of the cells.

Occasionally another type of microorganism is found, which is shown in oblique section in Figs. 11 and 12, and transverse section in Fig. 7. This also possesses a double cell wall, and the cytoplasm is granular near the membrane. However, the diameter is greater than that of the microorganism seen in Figs. 8, 9, and 10, and it never occurs in such large numbers.

DISCUSSION

A study of squash preparations of living epithelial cells indicates that cilia are absent, and that some form of symbiotic microorganism is present in

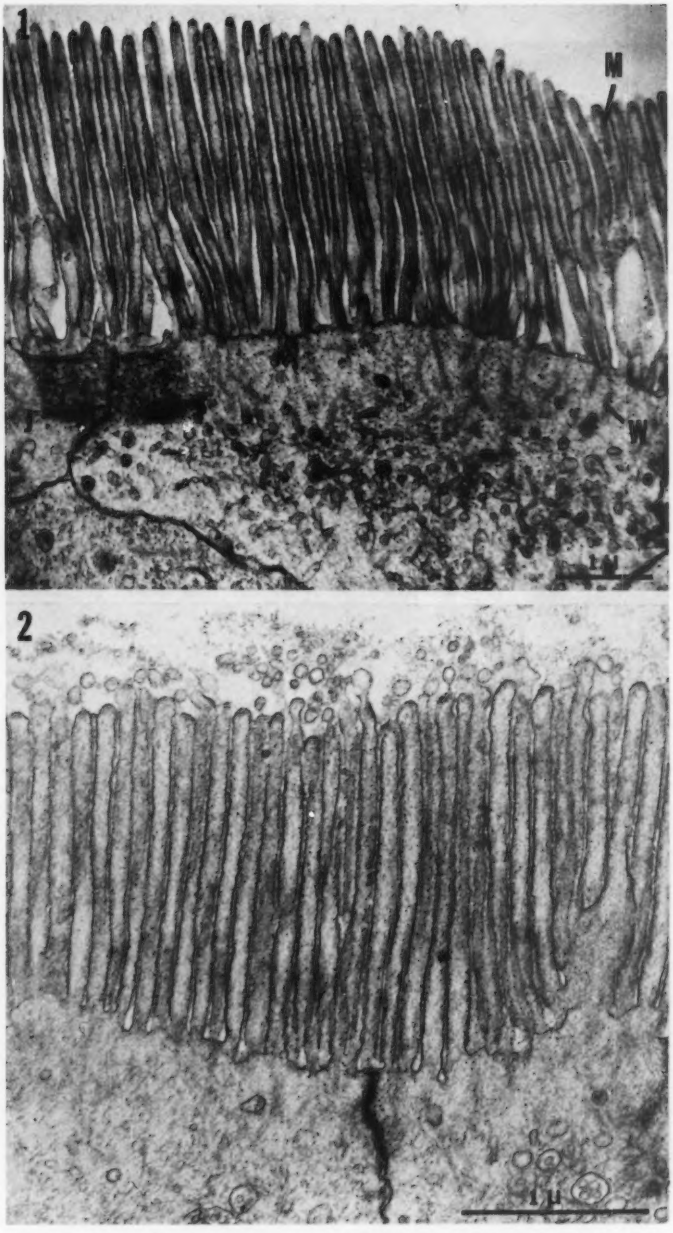

FIG. 1. Free epithelial border of pyloric caecum, showing microvilli. Abbreviations used for figures: brush border, B; longitudinal filaments of microvillus, F; interlacing filaments, I; junctional complex, J; zona occludens, ZO; zona adhaerens, ZA; macula adhaerens, MA; microvillus, M; microorganism, MO; terminal web, W.

FIG. 2. Free epithelial border of ileum, showing microvilli. The microvilli often occur in groups on a common stalk.

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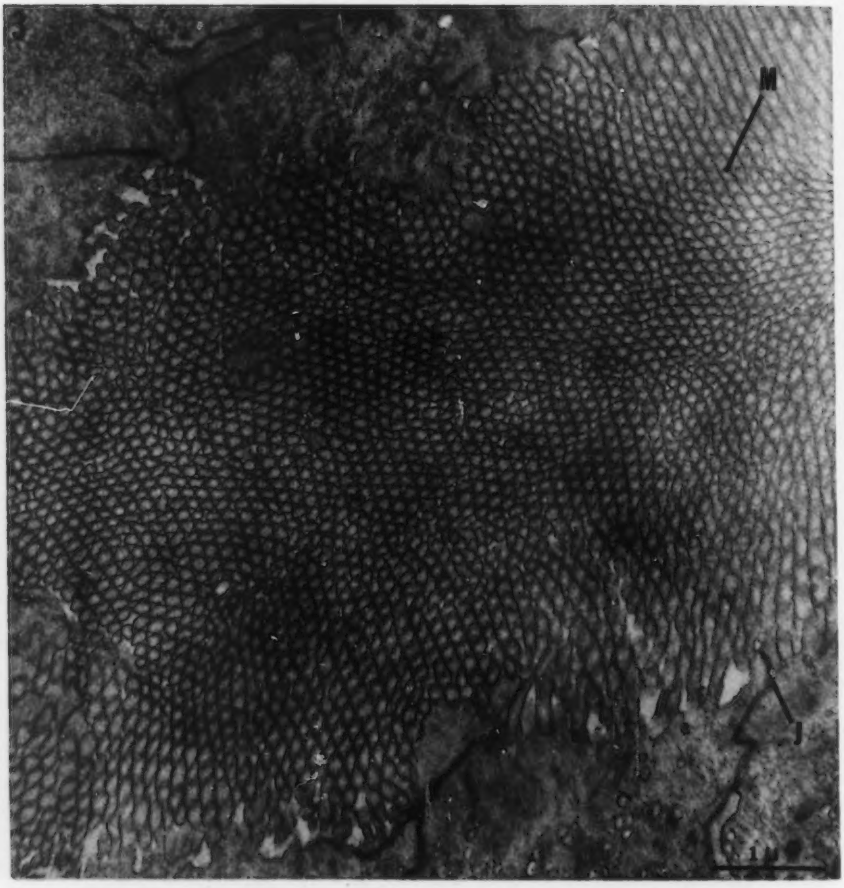
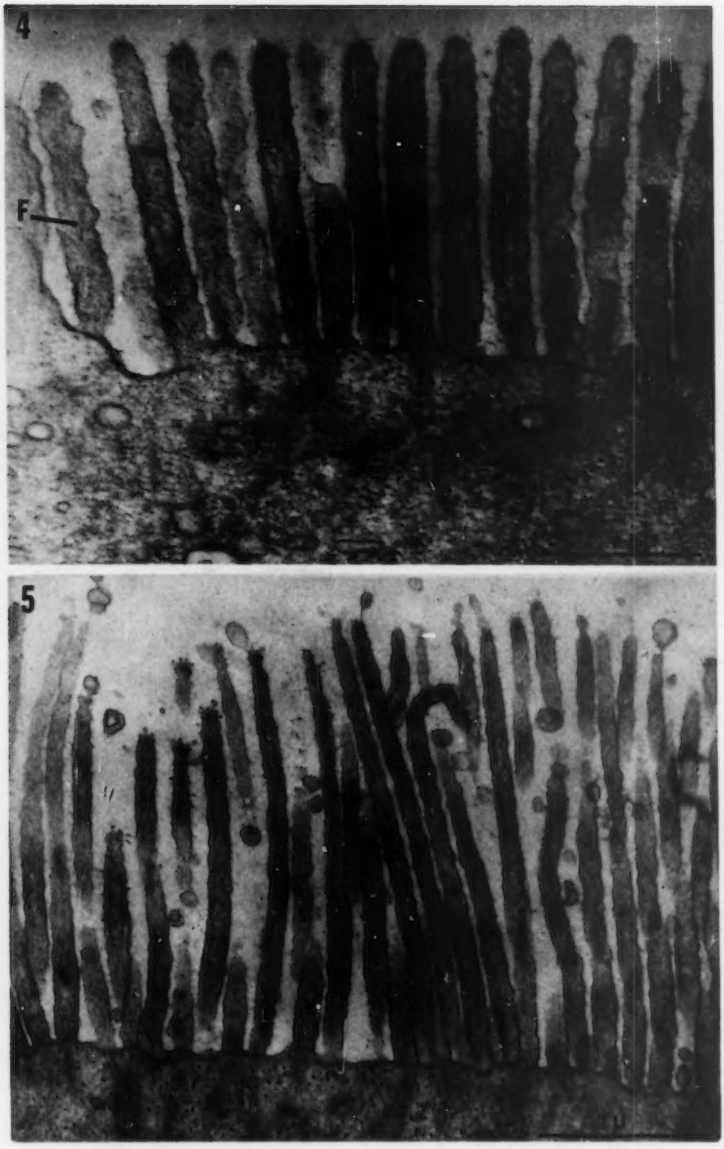
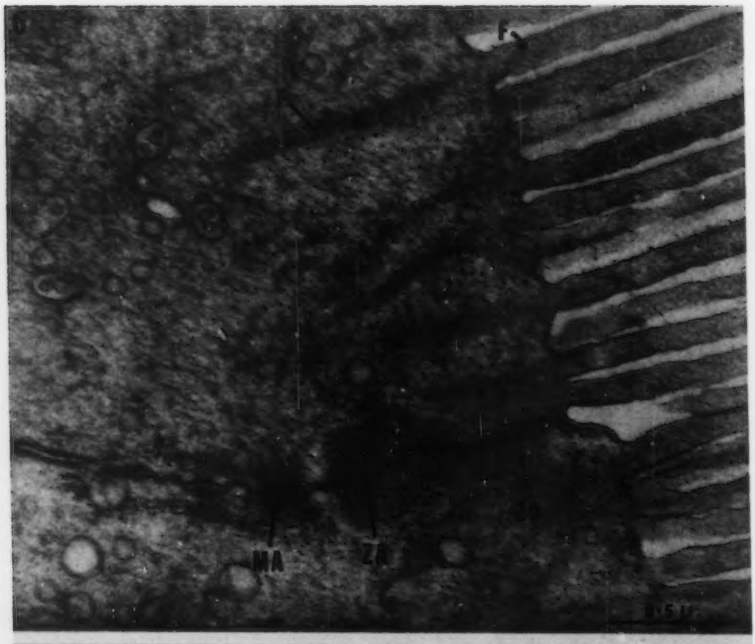


FIG. 3. Transverse section of microvilli from ileum. The section passes through the apical cytoplasm of the epithelial cells at the top left and bottom right of the figure. For explanation of abbreviations see Fig. 1.



FIGS. 4 and 5. Free epithelial border of the rectum, showing microvilli. Figure 4 is taken from a part of the border near the opening of a gland, where the microvilli are short and wide; Fig. 5 is taken from a part near the apex of a fold between two gland openings, where the microvilli are thinner and more elongated. For explanation of abbreviations see Fig. 1.



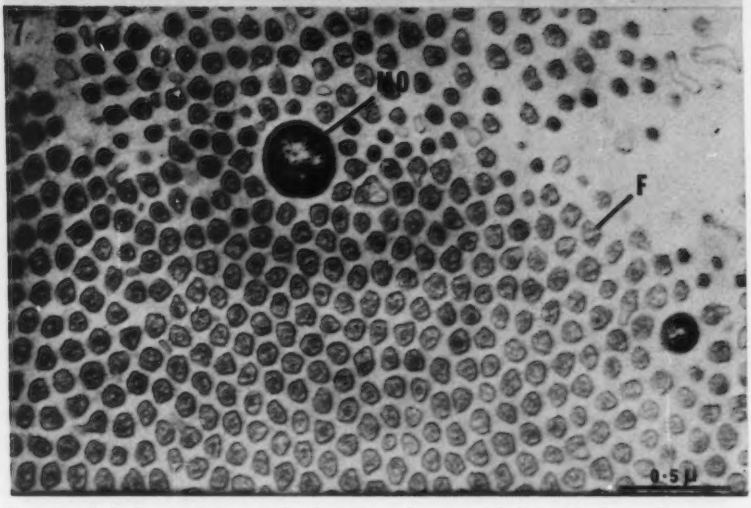


FIG. 6. Apical cytoplasm at the junction of two epithelial cells from the rectum, showing longitudinal filaments in the microvilli extending into the cells, and the regions of thickening at the cell junction.

FIG. 7. Transverse section of microvilli and two organisms from the rectum. For explanation of abbreviations see Fig. 1.

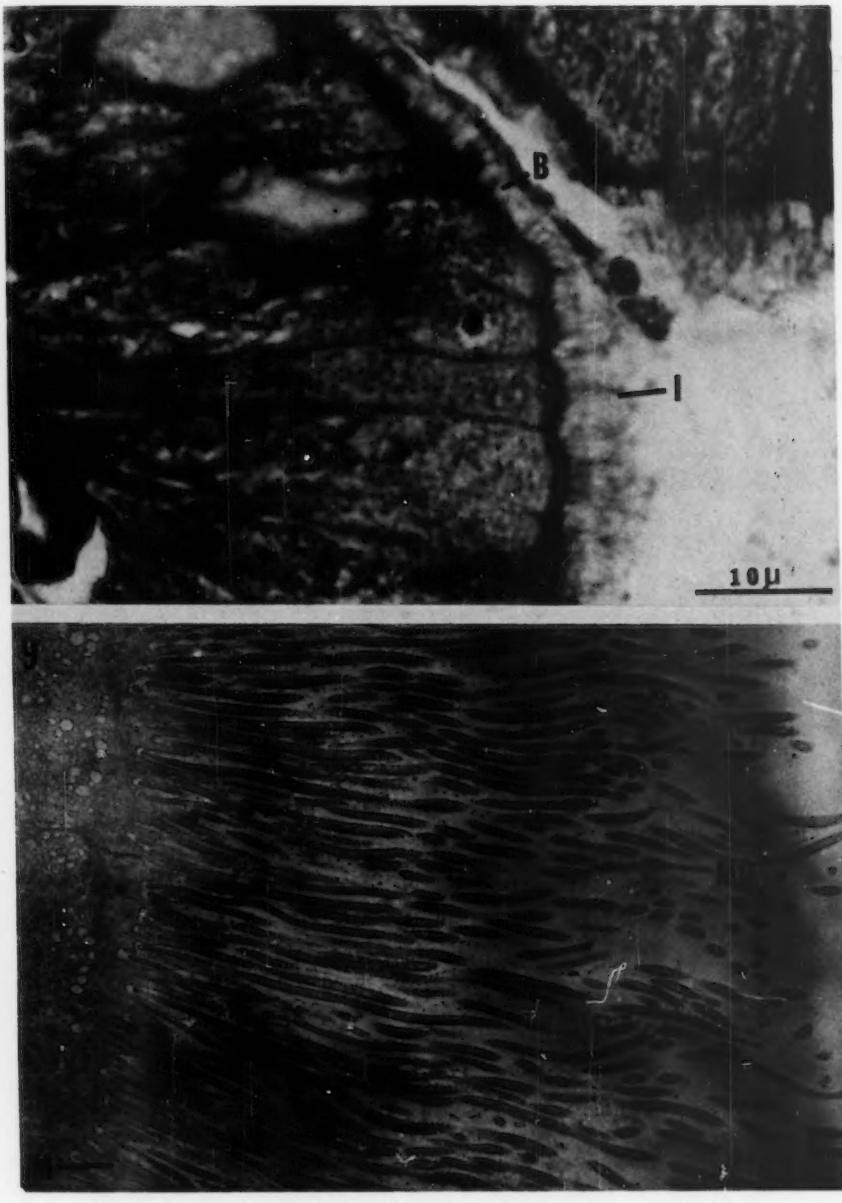


FIG. 8. Light micrograph of epithelial cells of the rectum, showing interlacing filaments along the free border except near the entrance of a gland at the top of the figure. Specimen preparation was the same as for Fig. 28 in Bishop and Odense (1966).

FIG. 9. Microorganisms aligned parallel to the microvilli in the rectum. For explanation of abbreviations see Fig. 1.

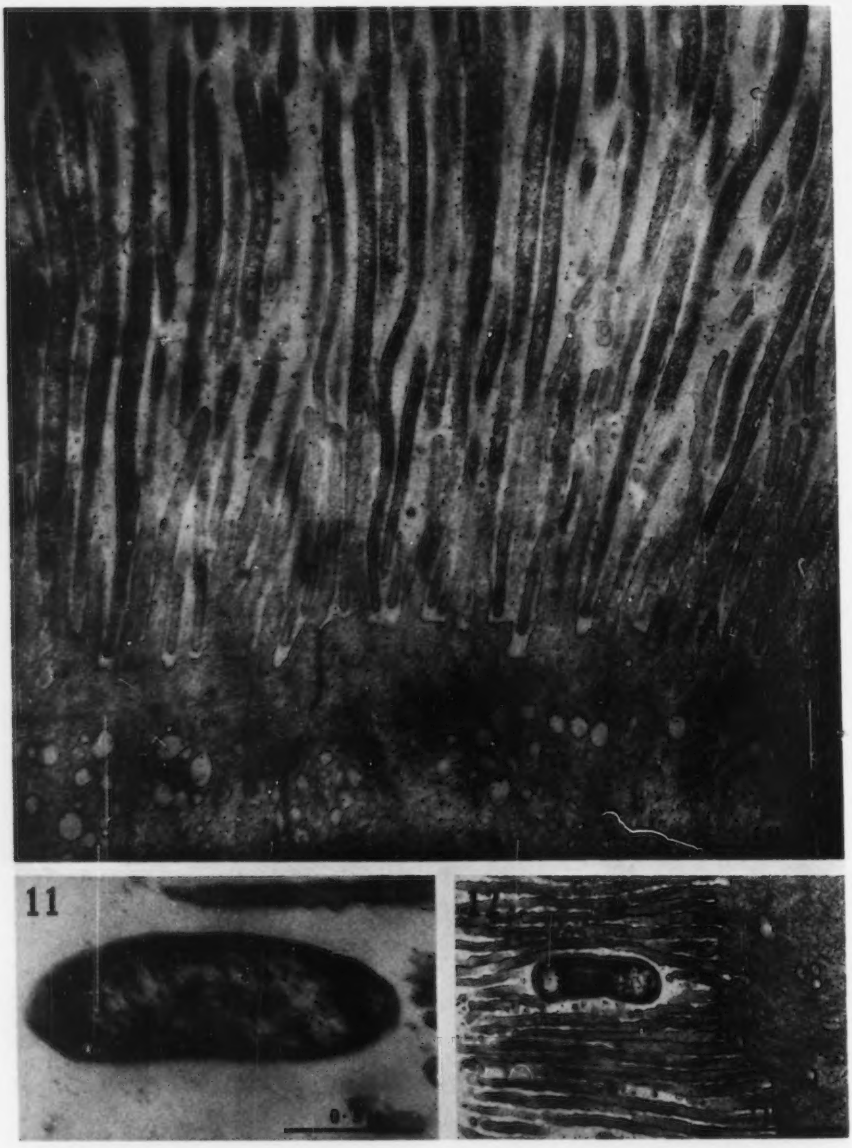


FIG. 10. Part of the same field as Fig. 9, taken at a higher magnification. The double envelope of the organisms can be clearly seen.

FIGS. 11 and 12. Microorganisms situated among the microvilli of the rectum.

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the rectum. The electronmicrographs show conclusively that microvilli are present, and that they are long compared with some mammals, which explains the prominent appearance of the border. The structure of the organisms in the rectum is like that of a bacterium, and the helical motion suggests that the organism may be a spirochaete. The light micrograph of the intestinal epithelial border of *Pterois volitans* (Al-Hussaini, 1949) looks similar to that of the rectum of *Gadus morhua*, suggesting that microorganisms may be present here also.

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Mouth and Body Form Relative to Feeding Ecology in the Fish Fauna of a Small Lake, Lake Opinicon, Ontario[1]

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ABSTRACT

In 14 cohabiting fish species in a small freshwater lake, mouth and body structures combine with food specializations and habitat preferences to greatly restrict interspecific competition within the fauna.

The species differ quantitatively in a large number of structures and, individually and in combination, these are clearly adapted for distinctive roles. The mouth is particularly plastic, varying in position, in aperture width, and in overall form, with structures as diverse as a scoop, a beak, and a tube being found. Six basic body types occur and these, combined with varying fin morphologies, result in a range of distinctive forms, including the following. *Micropterus salmoides*, with a compressed fusiform body and a wide mouth, is a strong-swimming, widely ranging piscivore. *Notemigonus crysopterus*, with a long, slender caudal peduncle, subfalcate pectoral fins, and a deeply forked caudal fin, has great maneuverability that permits it to catch individual zooplankters. *Lepomis macrochirus* is a "sedentary," gibbose-bodied water-hanger. *Umbra limi* has a stubby, cylindrical body that favours life in dense vegetation. *Labidesthes sicculus*, with an almost straight dorsal line to the body, a low dorsal fin, and a beak-like snout with tweezer-like teeth, is modified for surface feeding and leaping out of the water. *Ictalurus nebulosus* has chemotactile barbels that favour bottom feeding and paired fins that function partly as hydrofoils, keeping the body inclined downwards as the mouth sweeps the bottom.

The structural specializations give their owners a decided ecological advantage in certain situations. Only a few species, however, are limited by them to restricted ways of life. In most cases, a considerable measure of feeding flexibility is retained, presumably important for survival in cold temperate lakes.

INTRODUCTION

The objective of this paper is to describe and interrelate external morphological structure with way of life, feeding habits, and food. The fauna under investigation is that of a small (2200 acres) eutrophic lake, Lake Opinicon, Leeds County, Ontario.

Ichthyologists have paid little attention to the minor structural differences that separate cohabiting species of freshwater fishes, although the broad characteristics of the piscivore, the plankton feeder, the bottom feeder, and the swift and slow swimmer are well known. On this basis certain authors dealing with faunas have divided the species into a series of basic ecological types (Fryer, 1959; Lowe, 1964). Many freshwater fishes, however, differ from each other in minor morphological characters.

The situation in ichthyology contrasts to that in ornithology. Extensive research on birds has shown that minor differences in bill shape, form of wing, and length of tarsus are correlated with clear-cut differences in diet, feeding habits, and way of life (Lack, 1945; Hamilton, 1961; Osterhaus, 1962; and others). This knowledge has proven a valuable tool by means of which the ecology of species can be predicted. The mouth of fishes requires study since

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this is the structure whereby they obtain their food, and thus dictates the size and type of prey that can be handled. Its significance in leading to specialized feeding, and in reducing interspecific competition, needs assessing. Because there is a great deal of food overlap among cohabiting freshwater fishes, some workers have stated that these do not fit the Gausian concept (Gause, 1934) of ecological exclusion (Hartley, 1948; Larkin, 1956).

The present work draws upon a 4-year study of the food of the Lake Opinicon fish (Keast, 1965). A parallel study of the functional significance of differences in buccal and pharyngeal dentition, gill rakers, and intestinal structure in this fauna is near completion.

THE FAUNA

The species analysed in this study are as follows. Cyprinidae: *Notemigonus crysoleucas* (golden shiner), *Notropis heterodon* (blackchin shiner), *Pimephales notatus* (bluntnose minnow); Ictaluridae: *Ictalurus nebulosus* (brown bullhead); Umbridae: *Umbra limi* (mud minnow); Esocidae: *Esox lucius* (northern pike); Cyprinodontidae: *Fundulus diaphanus* (banded killifish); Percidae: *Perca flavescens* (yellow perch), *Percina caprodes* (log perch); Centrarchidae: *Lepomis macrochirus*, *L. gibbosus* (bluegill, pumpkinseed sunfish) (some hybridization), *Ambloplites rupestris* (rock bass), *Pomoxis nigromaculatus* (black crappie), *Micropterus salmoides* (largemouth bass); Atherinidae: *Labidesthes sicculus* (brook silverside). Four additional species occur in the lake, but were not included in the study. They are: *Ictalurus natalis* (yellow bullhead), which is structurally similar to *I. nebulosus*, relatively uncommon, and occupies a somewhat different habitat; *Pomolobus pseudoharengus* (alewife), a new immigrant which will be treated in detail elsewhere; *Etheostoma exile* (Iowa darter) and *Micropterus dolomieu* (smallmouth bass), both of which are very rare. Apart from dentition the characters of *Lepomis macrochirus* and *L. gibbosus* are closely similar, hence only the former is discussed.

METHODS

A series of criteria for comparing and measuring differences in mouth and body form were developed.

(1) *Standard length* (S.L.). The distance from the tip of the snout to the tip of the spinal column. This measurement, necessary for the calculation of body ratios, is taken as the criterion of body size. The food data quoted is based on total length, which includes the caudal fin (greatest length). A conversion factor for the two can be derived from Table I.

(2) *Mouth position.* Described as terminal, dorso-terminal or ventro-terminal.

(3) *Depth of mouth as seen from side.* The jaw angle is described as forming a deep, moderate, or shallow indentation.

(4) *Width of mouth aperture.* The distance across the inner sides of the open mouth at the jaw angles.

(5) *Premaxilla protrusibility.* In many fish the premaxilla is loosely attached to the maxilla by a median spinous process and a ligament. When the mouth opens, the premaxilla moves forward. This is possibly of some assistance in the seizure of prey, which is pulled inwards as the jaw closes. Fish with strong jaw margins have the premaxilla fused to the skull. Protrusibility is given as the percentage difference in distance from the anterior margin of the eye to the premaxilla as between the tightly closed and wide open mouth. The figures should be regarded as of relative value only, since fresh specimens were not always available for measurement.

(6) *Lower jaw extensibility.* When the mouth opens the lower jaw swings downwards and forwards, describing an arc. This is particularly noticeable when the mouth angle is strongly oblique; and the action may bring the lower jaw in advance of the upper to form a scoop-like structure. This is marked in some species. Alternatively, it may join with a protrusible premaxilla to form a tubular mouth. To obtain a measure of both the forward and downward movement, the distance from the anterior margin of the eye to the lower lip with mouth closed was deducted from the distance with the mouth open, and expressed as a percentage of the former. The figures are of broad comparative value only.

(7) *Dentition.* Only marginal dentition, that associated with the initial grasping of prey, is considered here.

(8) *Body height.* The deepest part of the body, excluding fins.

(9) *Body width.* The maximum width, which is characteristically in the region of the pectoral fins. In *I. nebulosus*, however, it is directly behind the head.

(10) *Body form.* The species are grouped into six categories: rounded fusiform, compressed fusiform, foreshortened tubular, elongate tubular, subgibbose, and gibbose (Fig. 1).

(11) *Pectoral-pelvic distance.* The horizontal distance between the midpoints of the bases of the paired fins, expressed as percentage of standard length.

(12) *Caudal peduncle length.* The horizontal distance from the anus to the end of the spinal column, expressed as percentage of standard length (Gray, 1953).

(13) *Fin form.* The basic types of pectoral fins occurring in this fauna are illustrated in Fig. 1. Nomenclature for these, as well as for caudal fin types, follows that of Norman and Greenwood (1963), with minor modifications. Dorsal and anal fins are described in terms of basal length, height or depth, and general shape.

(14) *Fin movements.* These are described in some detail because of their importance in maneuvering.

The measurements given in the study are based on 15 adult members of each species.

FOOD DATA

Series of the different size (year class) categories of each species were collected from Lake Opinicon at monthly intervals from May to October inclusive from 1962 to 1965. The number of stomachs examined ranged from 250 to 600 per species. Other food studies, involving similar numbers, were carried out in three other Ontario waterways: Jones Creek near Brockville, Fish Lake near Picton, and Kearney Lake in Algonquin Park. Thus, for about two-thirds of the species, comparable information was obtained. Data for other parts of the species range is from the literature. An understanding of food changes with growth is desirable since a structure could be of greater importance at one stage of life than another.

Feeding, general behavior, and habitat distribution of the Lake Opinicon fishes was studied in the lake using a canoe and snorkel. Indoor studies were conducted in large aquaria.

BODY AND FIN FORM IN FISHES

A brief review of existing knowledge of the significance of the common kinds of body forms found in fishes is a prerequisite.

The following is synthesized from various sources, but particularly Gray (1933, 1953, 1960); Harris (1936, 1938); Nursall (1958); Bainbridge (1958, 1960); Lagler et al. (1962); Young (1962); and Norman and Greenwood (1963).

The fusiform body, moderately elliptical in cross section (Figs. 1–3) is physically the most efficient for rapid progression through a liquid medium; hence, it is characteristic of fish species that swim more or less continuously

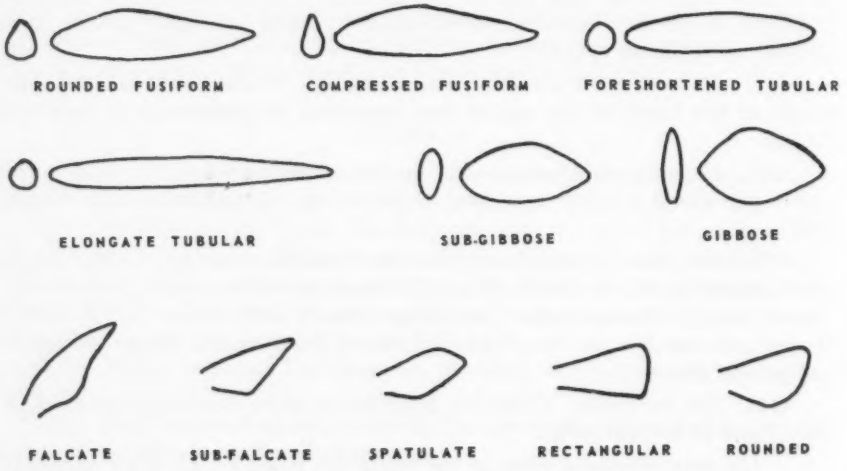

FIG. 1. Different kinds of body shapes, transverse sections and side views (upper), and kinds of pectoral fin (lower) of fishes of Lake Opinicon, Ontario.

and range widely. Propulsion is by means of alternating lateral contractions of the muscular body, plus the movements of the caudal fin, the latter providing a significant part of the forward thrust, estimated at 40% in the whiting, *Gadus merlangus* (Gray, 1933). There is a narrow, flexible caudal peduncle, muscular in generalized fishes, but largely tendinous in the pelagic tunas. The caudal fin is characteristically forked, thus serving to reduce turbulence and increase the fin's aspect ratio (ratio of span to length). However, for a fish accelerating to high speed from rest, too high an aspect ratio would cause the fin to stall. In such fish then, the caudal fin is usually wedge-shaped rather than crescentic, and, although it may be deeply indented, the posterior margin is convex rather than concave (Fig. 3). Generalized fishes like *Micropterus dolomieu* and *P. flavescens*, accordingly, have an aspect ratio between 2 and 4, whereas this reaches 6.1 in the continuously swimming marine tuna (Nursall, 1958). Furthermore, bass and perch, and others like them, can move the individual rays of the caudal fin independently. This facilitates hovering. Fish with truncated and rounded tails (and a low aspect ratio) are comparatively slow swimmers and, although capable of sudden bursts of speed, are unable to swim for long periods at high speed (Norman and Greenwood, 1963).

Paired and median fins function as stabilizing and maneuvering organs, the pectorals being the main medium whereby turning, banking, rising, diving, and stopping are accomplished. In swift fishes the pectoral fin is usually long and falcate, whereas in slow swimmers it is commonly rectangular, rounded, or spatulate (Figs. 1, 3). Median fins have a basic role as vertical keels. In species where the dorsal fin can be raised and lowered, it is elevated at the beginning of a turn, thus increasing the yawing movement (lateral oscillations about the path of progression) produced by the asymmetrical action of the body muscles, the unilateral braking action of a pectoral fin providing the fulcrum about which the turn is completed.

The gibbose body form (Fig. 1) has evolved independently in many suborders. Its possessor is "a very stable swimmer, since its large lateral area limits rolling, while pitching rotations can be controlled by the pectoral and pelvic fin forces: asymmetrical vertical forces can also be used to tilt the body laterally at any desired angle. The large lateral area demands large dorsal and anal fins to provide static stability in yaw during forward movement: normal propulsion is often produced by rowing with the pectoral fins". (Harris, 1938).

Where the pectoral fins are used for active propulsion, the amount of fin musculature is large with the adductors forming some 65% of the whole. There is free articulation of the first fin ray on the scapula to permit a "feathering" return motion. Fishes in which the pectorals function primarily as brakes have less fin musculature, most of the weight being made up of the adductors. Here the first fin ray, which takes most of the water force, rotates outward on a simple roller-bearing joint (Harris, 1938). Breder (1924) has drawn attention to a function of the pectorals in hovering fish like *L. macrochirus*: they move in rhythm with the respiratory movements, thus checking the forward thrust that results from expulsion of water from the operculum.

The pelvic fins are far forward in the gibbose fishes functioning here to neutralize the lift force of the relatively high pectorals. A compromise is involved: if the pelvics were far back, their downward force would depress the tail and lift the head (positive pitch). On the other hand if the pectorals were lower, their effectiveness as brakes would be reduced. Long-bodied teleosts with widely separated paired fins do not have this problem. The pectorals are ventral and situated well in front of the center of gravity, instead of close to it. The posteriorly located (abdominal) pelvic fins keep the tail end of the body from tipping up (negative pitch) when the fish stops (Lagler et al., 1962).

THE SPECIES, THEIR MORPHOLOGICAL CHARACTERISTICS, FEEDING HABITS, AND FOOD

The differences in body size of the species are indicated diagrammatically in Fig. 2, typical large adults being shown. The average standard lengths are given in Table I. The species range from large piscivores like *E. lucius*, which in this lake reaches slightly over 500 mm, down to small minnows like *N. heterodon* with a standard length of 50–55 mm.

The body and mouth forms of the species are illustrated in Figs. 3 and 4, their characteristics being compared quantitatively in Tables I and II.

UMBRIDAE

MUD MINNOW

In *Umbra limi*, the aperture of the terminal mouth is relatively wide, averaging 4.7 mm (8% S.L.) in the adult fish (Table I). The premaxilla is fixed, giving strength, the jaws are somewhat heavy, and the marginal dentition, consisting of a double row of sharp conical and recurved teeth, is moderately strong. The mouth is scoop-like (Fig. 4), and the feeding action is a snapping one.

The dominant foods are as follows. Lake Opinicon: Chironomid larvae and pupae (10–35% volume); Gastropoda (up to 40%); Ostracoda (5–10%); Amphipoda (up to 20%); small Ephemeroptera nymphs (up to 20%); Trichoptera larvae (up to 15%); and Coleoptera (up to 15%). Fish Lake: similar but less emphasis on chironomid larvae and slightly more on Ostracoda, small Odonata nymphs, and Hydracarina. Jones Creek: similar but Isopoda and Odonata nymphs more, and Ephemeroptera nymphs, less important. First-year fish (30–60 mm S.L.) have the same diet as adults but Cladocera make up a small proportion of the food (up to 20% volume). Such studies as have been carried out on the food of *U. limi* in other parts of its range (Pearse, 1916; and others) substantiate these findings. *Umbra limi* thus obtains its food from the bottom and rooted vegetation. The prey is relatively large and hard-bodied (note the wide gape, strong jaws, fixed premaxilla, and well-developed marginal (and buccal) dentition).

Measurements show that the body form of *U. limi* is foreshortened tubular (Fig. 3) the height: width ratio being 1.4 (Table I). In accordance with this, the paired fins are widely spaced and ventral. The single dorsal fin is medium-based,

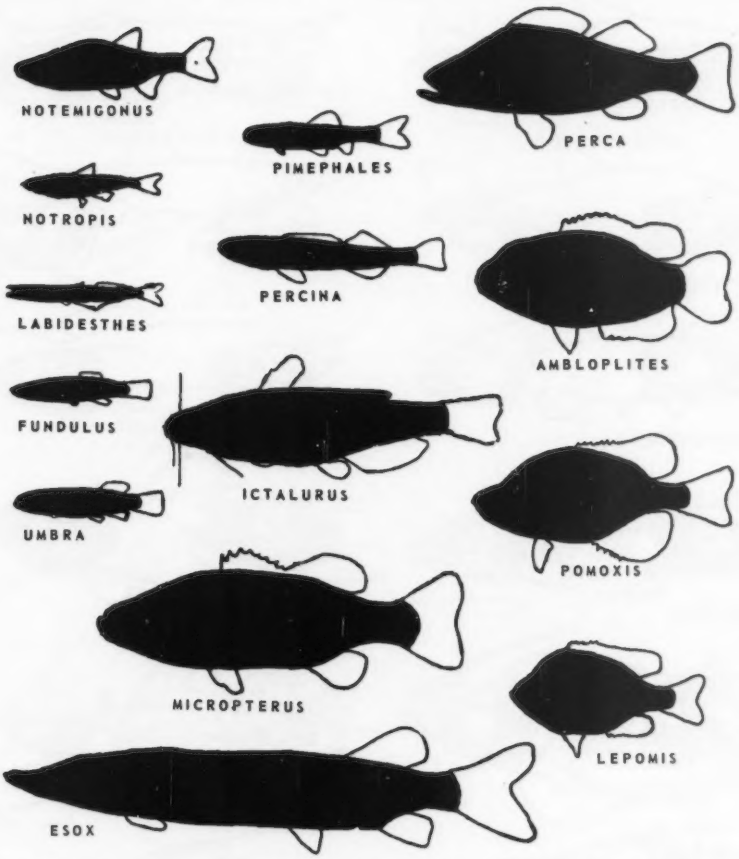

FIG. 2. General differences in body size of typical adult members of the cohabiting fish species in Lake Opinicon, Ontario. *Micropterus* and *Esox* are $\frac{5}{8}$ of natural size.

of intermediate height, rounded, and placed posteriorly; the anal is short-based, deep, and rounded. The whole body is thick, this presumably being of advantage amongst the tangled vegetation that forms its preferred habitat; this body form may also explain its ability to burrow into the soft mud to hibernate and escape predators. On the other hand, *U. limi* is a slow swimmer, as the thickened peduncle and rounded caudal fin indicate. The posterior dorsal and anal fins could supplement the propulsive action of the tail during sudden escape movements.

Aquarium studies reveal that *U. limi* has the characteristic habit of holding still in midwater for long periods, often with the body inclined upwards. The former is achieved not by a regular beat of the pectoral fins but by a

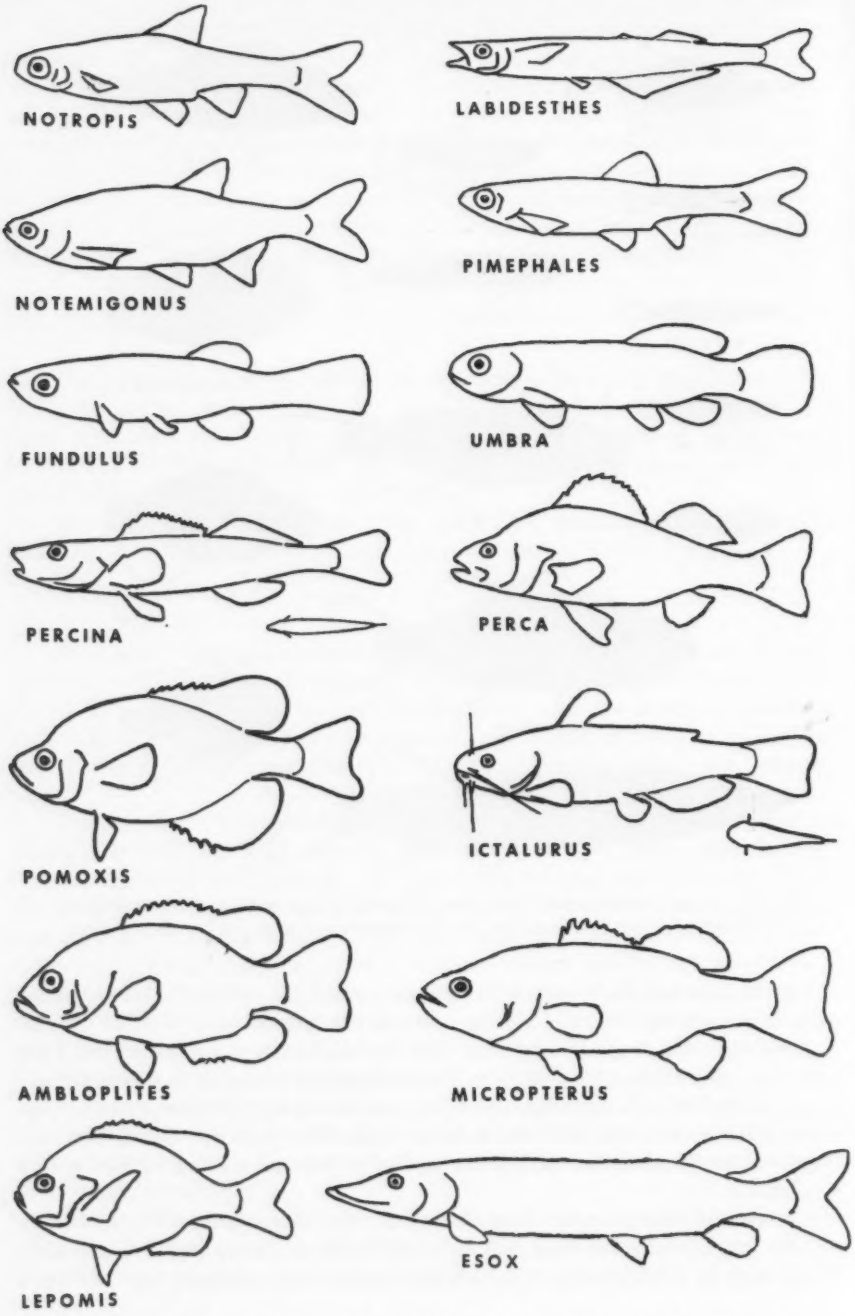

FIG. 3. Comparative body and fin morphology of fishes of Lake Opinicon, Ontario.

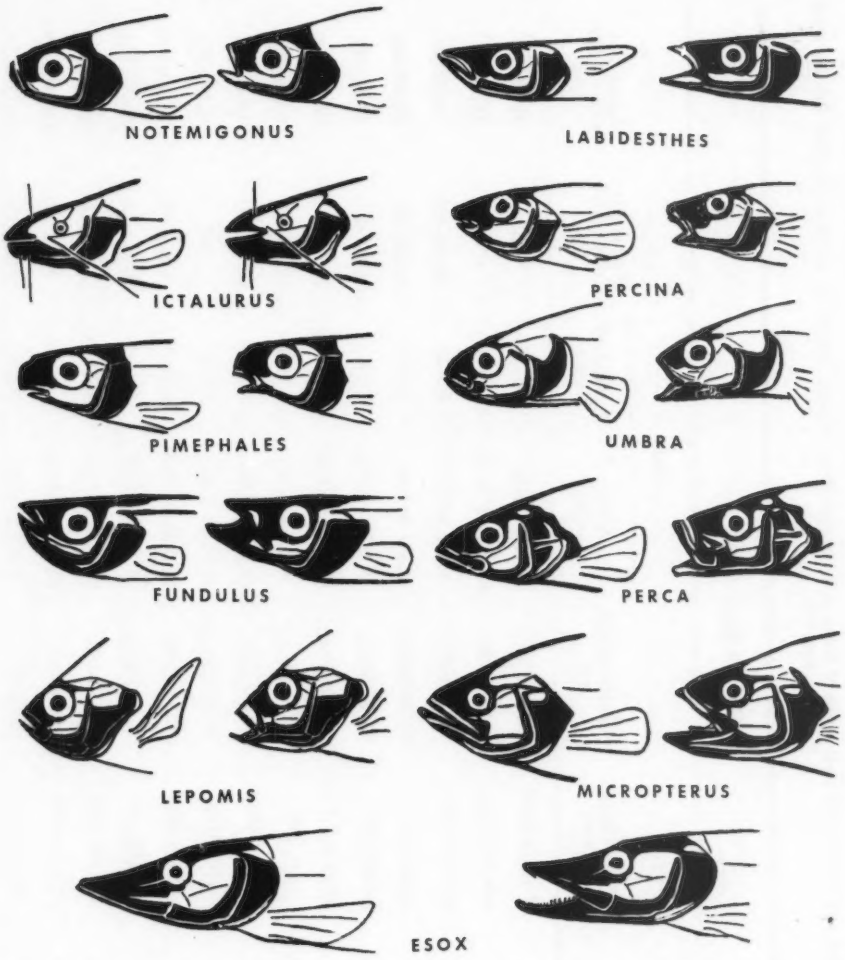

FIG. 4. Mouth morphology (closed on left, open on right) of fishes of Lake Opinicon, Ontario

continuous rippling movement (Table II), undulating waves passing anteroposteriorly across the extended fin surface. There is a simultaneous oscillation of the large dorsal fin. By contrast, terminal movements in the expanded anal fin are slight. When feeding, *U. limi* maneuvers close to its prey, then seizes it with a sudden strike. This, and the subtle fin movements which cause a minimum of turbulence, may be significant in stalking prey with the capacity for making rapid escape movements (such as Ephemeroptera nymphs and Coleoptera).

TABLE I. Quantitative data on size and mouth and body form of fishes of Lake Opinicon, Ontario (based on series of 15 adult fishes of each species).

Species	Size and mouth form					
			Gape			
	Total length (*mm*)	Standard length (*mm*)	Width (*mm*)	% standard length	Premaxilla protrusibility (%)[b]	Lower jaw extensibility (%)[b]
Umbra limi	71(62–78)[a]	59(52–65)	4.7(2.9–6.5)	8(7–10)	Nil	78(75–90)
Esox lucius	580(410–754)	500(350–650)	60.0(49.5–78.0)	12(11–12)	Nil	34(29–39)
Notemigonus crysoleucas	120(115–137)	96(92–110)	4.6(4.0–6.6)	5(5–6)	49(45–55)	74(63–82)
Notropis heterodon	62(58–66)	51(48–54)	3.2(2.4–3.6)	6(5–6)	45(42–48)	82(70–91)
Pimephales notatus	80(76–82)	65(62–67)	3.1(3.1–3.6)	5(5–6)	24(21–27)	56(51–62)
Ictalurus nebulosus	187(150–250+)	150(120–200+)	19.5(14.4–30+)	13(12–15)	Nil	63(54–66)
Fundulus diaphanus	74(71–77)	62(60–65)	3.9(3.0–4.2)	6(5–6)	35(28–40)	65(54–74)
Perca flavescens	159(147–295)	135(125–250)	10.8(8.8–5.0)	8(7–10)	20(18–29)	55(46–78)
Percina caprodes	104(93–116)	90(80–100)	4.5(3.2–5.0)	5(4–5)	Nil	61(50–70)
Micropterus salmoides	540(420–600)	450(350–500)	64.0(50.0–85.0)	16(16–17)	17(16–18)	104(90–118)
Lepomis macrochirus	170(158–189)	135(125–150)	8.1(6.2–12.0)	6(5–8)	48(42–58)	100(98–105)
Ambloplites rupestris	176(164–189)	140(130–150)	16.8(13.0–21.0)	12(10–14)	20(16–24)	107(99–112)
Pomoxis nigromaculatus	202(164–277)	160(130–220)	14.4(10.0–22.0)	9(8–10)	39(38–40)	123(114–130)
Labidesthes sicculus	76(72–91)	65(62–78)	3.2(2.5–3.9)	5(4–5)	15(11–18)	38(33–42)

Species	Body form				
	Width : length ratio	Height : length ratio	Height : width ratio	Pectoral-pelvic distance, % of standard length	Caudal peduncle, % of standard length
Umbra limi	16(15–17)	23(23–24)	1.4(1.3–1.5)	26(24–28)	28(27–29)
Esox lucius	13(12–15)	18(16–19)	1.3(1.0–1.4)	25(24–26)	23(22–24)
Notemigonus crysoleucas	12(12–13)	24(23–25)	2.0(1.9–2.0)	22(21–23)	35(34–37)
Notropis heterodon	13(13–14)	23(22–24)	1.7(1.5–1.7)	21(20–22)	32(29–34)
Pimephales notatus	15(14–15)	20(19–22)	1.4(1.3–1.4)	24(23–26)	32(32–34)
Ictalurus nebulosus	20(19–21)	25(24–26)	1.2(1.0–1.3)	23(20–25)	37(34–40)
Fundulus diaphanus	15(14–15)	19(19–20)	1.3(1.3–1.4)	17(17–18)	35(35–36)
Perca flavescens	16(16–17)	27(26–27)	1.6(1.6–1.7)	5.2(5.1–5.4)	32(32–33)
Percina caprodes	14(14.0–14.2)	17(17–18)	1.2(1.1–1.2)	3.4(3.0–3.9)	37(36–38)
Micropterus salmoides	18(18–20)	37(36–39)	2.1(2.0–2.5)	0.6(0.4–0.7)	34(33–35)
Lepomis gibbosus macrochirus	21(21–22)	52(51–53)	2.6(2.5–2.9)	6.0(5.4–6.2)	40(40–42)
Ambloplites rupestris	19(18–19)	41(40–42)	2.1(2.1–2.2)	3.2(3.0–4.0)	41(39–42)
Pomoxis nigromaculatus	15(15–16)	42(41–44)	2.8(2.7–2.9)	0.7(0.6–0.8)	49(47–51)
Labidesthes sicculus	9(8.9–9.1)	12(11–12)	1.3(1.2–1.4)	16(15–16)	48(47–48)

[a]Average and range.

[b]See text.

TABLE II. Mouth, body, and fin structures of fishes of Lake Opinicon, Ontario.

Species	Body form	Mouth			Caudal peduncle form	Pectoral fin		Caudal fin
		Position	Aperture	Form		Form	Movement	
Umbra limi	Foreshortened tubular	Terminal	Moderate	Scoop	Thick	Rectangular	Undulating	Rounded truncate
Esox lucius	Elongate tubular	Terminal	Wide	Broad beak	Short	Rectangular	Undulating when small	Deeply forked; rounded tips
Notemigonus crysoleucas	Compressed fusiform	Dorso-terminal	Narrow	Scoop	Long and slender	Sub-falcate	Synchronized beat	Deeply forked; pointed tips
Notropis heterodon	Compressed fusiform	Dorso-terminal	Narrow	Scoop	Long and slender	Sub-falcate	Synchronized beat	Deeply forked; pointed tips
Pimephales notatus	Rounded fusiform	Ventro-terminal	Very narrow	Tubular	Long and slender	Sub-falcate	Synchronized beat	Deeply forked; rounded tips
Ictalurus nebulosus	Flattened head; compressed body; sensory barbels	Terminal	Wide	Broad but low scoop	Short	Rounded	Extended as hydrofoils; intermittent, synchronized beat	Emarginate
Fundulus diaphanus	Rounded fusiform	Dorso-terminal	Narrow	Sub-tubular	Long	Spatulate	Independent beat; rapid	Truncate
Perca flavescens	Compressed fusiform	Terminal	Moderate	Scoop	Moderately long	Rounded	Alternating beat, horizontal plane; mild wrist action	Shallowly forked
Percina caprodes	Elongate tubular; snout knob	Ventro-terminal	Narrow	Small; snapping action	Moderately long	Spatulate	Synchronized, oar-like sweep; bottom props	Emarginate
Micropterus salmoides	Compressed fusiform	Terminal	Very wide	Cavernous scoop	Functionally short	Rounded	Alternating beat; minor wrist action	Shallowly forked, rounded tips
Lepomis macrochirus	Gibbose	Terminal	Narrow	Sub-tubular, snapping or nipping action	Functionally short	Falcate, large	Independent beat; marked wrist action	Shallowly forked, rounded tips
Ambloplites rupestris	Sub-gibbose	Terminal	Wide	Scoop	Functionally short	Rounded	Independent beat; slight wrist action	Shallowly forked, rounded tips
Pomoxis nigromaculatus	Gibbose	Dorso-terminal	Moderate	Scoop	Functionally short	Rounded, large	Independent beat; slight wrist action	Shallowly forked, rounded tips
Labidesthes sicculus	Elongated tubular	Dorso-terminal	Narrow	Fine beak	Long	Falcate, high on body	Independent beat; wide sweeping movements	Deeply forked; pointed tips

ESOCIDAE

NORTHERN PIKE

In *Esox lucius*, the mouth aperture is wide, averaging 60 mm in a 500 mm fish (i.e. 12% S.L.). The mouth is terminal. From the side, the jaw angle forms a deep indentation, this being achieved by a flattening of the head to produce a snout similar to a "duck bill". The premaxilla is fused and the lower jaw moves in a downward, rather than a downward and forward plane. The jaws are massive. The premaxilla bears a single row of small, slender, conical teeth, strongly recurved; these are duplicated on the lower jaw but the lateral "canines" are much enlarged, compressed, triangular in shape, and have attenuated, recurved points. The marginal (and buccal) teeth are so angled that, once grasped, the prey can only move backwards towards the throat. Like other fish, *E. lucius* begins life as a plankton feeder but this phase is brief and limited to fingerlings below 30 mm in length. The species is largely piscivorous beyond 45 mm (Hunt and Carbine, 1950). Size of the prey increases as the pike grows; in Lake Opinicon the smaller fish take minnows (*P. notatus*, *N. heterodon*) and darters (*Etheostoma exile*), the larger fish sunfish (*L. machrochirus*) and alewife (*Pomolobus pseudoharengus*). Pike also occasionally take take small birds and rodents.

The body of *E. lucius* is elongated tubular, having a height:width ratio of 1.3. Accordingly, the pectorals and pelvics are widely separated and ventral. The single dorsal fin is high and short-based, the anal short-based, deep, and rectangular. Placed far posteriorly, these fins supplement the deeply forked caudal fin in forward propulsion. The caudal peduncle is short, but this is compensated for by the flexibility of the posterior part of the trunk. The concentration of power represented by the combined dorsal, anal, and caudal fins probably underlies the ability of *E. lucius* to make swift strikes from rest, for prey is usually rushed from a short distance away. The tubular body form is also effective in negotiating vegetation.

In the adult pike the extended, or semi-extended, pectoral fins, ventral in position and rectangular in form, have a stabilizing function. In small fish, however, they exhibit pronounced rippling movements similar to those that have been observed by us in *U. limi* and *Esox americanus vermiculatus*.

All aspects of the body and mouth form of *E. lucius* show great specialization for a piscivorous way of life.

CYPRINIDAE

The cyprinids are characterized by the absence of marginal teeth and possession of soft fin rays.

GOLDEN SHINER

In *Notemigonus crysoleucas*, the mouth aperture is relatively narrow, averaging 4.6 mm in adults (5% S.L.). The mouth is dorso-terminal. From the side, the jaw angle forms a shallow indentation, though the latter is compensated for by a protrusible premaxilla and extensible mandible to

produce a scoop-like structure. In Lake Opinicon the main foods are Cladocera, which account for 20–90% of the volume, depending on the month, flying insects (20%), chironomid pupae (10–30%), along with some filamentous algae (important in late summer). Very small numbers of Odonata nymphs, Coleoptera, and Hydracarina are taken. These foods are also characteristic in Fish Lake, where Mollusca also occur in the diet, Kearney Lake, and Jones Creek, as well as in Wisconsin (Pearse, 1916), Oklahoma (Carter, 1949), and various other parts of the range (Dobie et al., 1948). There is no significant difference in the basic diets of adults and young. It is obvious that *N. crysoleucas* is almost entirely a middle water and surface feeder, a prediliction that can readily be observed in aquaria. The position of the mouth is an adaptation for this as is the narrow gape for selecting items of relatively small size.

The body is compressed fusiform, the height:width ratio being 2.0. The caudal peduncle is long and slender and the caudal fin deeply forked. The pectorals and pelvics are widely separated and placed low on the body. A feature is the angular form of the fins. The pectorals are subfalcate, the short-based dorsal is high and triangular, and the short-based anal is deep and triangular.

Individually and in combination the body characters of this species are those of a very mobile fish and in Lake Opinicon the schools move over wide areas. The major feature, however, is its great maneuverability, the individuals twisting and turning with great rapidity as they feed. Small Cladocera are snapped up individually. Marked mobility of the fins is apparent at this time, the pectorals moving with sharp, synchronized, oar-like beats, and the dorsals being constantly raised and lowered as they initiate turns. *Notemigonus crysoleucas* does, on occasions, swim slowly or hold still, at which time position is maintained by a slow beat of the pectorals, a fluttering action of the upper lobe of the caudal fin, and an occasional twitching of the dorsal and anal fins.

BLACKCHIN SHINER

Notropis heterodon, in its mouth, body, and fin forms, is a small replica of the foregoing. Adults reach a standard length of only 50–55 mm, compared with 110 mm in *N. crysoleucas*. The gape, averaging 3.2 mm (6% S.L.), restricts the species to small food items such as Cladocera (from 20–50% volume), flying insects (10–80%), and filamentous algae.

The height:width ratio of the body (1.7) is somewhat less than that of *N. crysoleucas*, whereas the pectoral-pelvic distance and caudal peduncle are somewhat shorter. The significance of these minor differences is not clear. However, *N. heterodon* is much less widely ranging, being found mainly in the shallows close to shore. Like *N. crysoleucas* it is highly maneuverable.

BLUNTNOSE MINNOW

The mouth is ventro-terminal, tubular, and narrow, the aperture averaging only 3.1 mm (5% of the S.L.). In Lake Opinicon *Pimephales notatus* subsists almost entirely on organic detritus from the bottom (20–50% volume),

small chironomid larvae (5–30%), and Cladocera (10–75%). In Kearney Lake the stomachs contain mostly chironomid larvae and algae (Sheppard, 1965). "Bottom ooze" is an important item of diet in most parts of the range, as recorded by Kraatz (1927) for Ohio and Starrett (1950) for Iowa. Thus the diet reflects this species structural specializations for bottom feeding. Aquarium observations confirm its ability to take Cladocera from the water column and show that it is quite unable to get its mouth into the necessary position to pick up items from the surface.

The body form of this species is more rounded and tubular than that of the other two cyprinids in the lake, the height:width ratio being 1.4. The pectoral–pelvic distance and relative length of the caudal peduncle are comparable. The fins, especially the caudal, are more rounded. Although retaining a measure of maneuverability, *P. notatus* definitely does not have the capacity for rapid acceleration, the restless mobility, nor the graceful gliding movements of *N. crysoleucas* and *N. heterodon*. It is a rather local species in Lake Opinicon, being found in the shallows over areas of sandy and muddy bottom.

ICTALURIDAE

The ictalurids are adapted for life in muddy water and/or nocturnal feeding, depending on chemosensory barbels, rather than vision, to locate food. The eyes are small and sight is poorly developed.

BROWN BULLHEAD

In *Ictalurus nebulosus*, the terminal mouth aperture extends for almost the entire width of the broad, flat head, averaging 19.5 mm (13% S.L.) in fish of 150 mm. From the side, the jaw angle forms a shallow indentation. The premaxilla is fixed, and the marginal dentition consists of several ill-defined rows of relatively long, conical, slightly recurved teeth.

In Lake Opinicon, fish 30–60 mm total length feed mainly on chironomid larvae (up to 50% volume), Cladocera (60%), Ostracoda, Amphipoda, Hemiptera, and small Ephemeroptera. These same items characterize the 70–120 mm group but Cladocera are replaced by increased amounts of Hemiptera, Ostracoda, and, in July, some newly hatched fish fry. Large fish of 130–240 mm total length feed on chironomid larvae (up to 80% volume), Mollusca (40%), Ostracoda (30%), small crayfish (20%), and Amphipoda (16%). In Jones Creek the diet is similar but leeches replace decapods. This versatile pattern of feeding agrees with findings in other parts of the species range (Baker, 1916; Nurnberger, 1930; and Moore et al., 1934).

Ictalurus nebulosus is hence mainly a bottom feeder, obviously capable of handling small items (chironomids) as well as larger hard-bodied prey. In aquaria, feeding is done by "nosing" along the bottom at a declined angle, somewhat in the manner of a vacuum cleaner, the ventral barbels just touching the substratum. When food is detected, the fish turns quickly and seizes it with a snapping action. A degree of suction appears to be involved in the case of smaller prey because a fish will often draw up detritus, mouth it, and then expel the residue. Since the mouth is terminal the fish may have to

tilt to the vertical to seize an item on the bottom. The great dependence of this species on its chemotactile barbels is seen when aquarium fish are presented with small pieces of liver. They immediately go into vigorous searching movements of a random nature, threshing about until one happens to touch the item with its barbels or body. As often as not the object will be missed and fall to the bottom, to be obtained later by systematic searching.

The body of *I. nebulosus* is flat anteriorly, compressed posteriorly, and the pectorals and pelvics are widely separated. The whole posterior half of the body is used in propulsion, the swimming movements being sinuous and sub-anguilliform. The caudal fin is large and emarginate, as in many relatively slow-swimming fish. The high, short-based, dorsal fin is far anterior at the point where the body narrows where it can be of maximum advantage both as a keel and a turning aid. The anal is posterior, long-based, deep, and rounded, and such a fin in the catfishes, like the heterocercal tail of sharks, gives lift and negative pitch (Young, 1962). The paired fins are shark-like, being large, low on the body, and held outwards in a horizontal plane. Although they beat periodically with a synchronized action their main function is that of hydrofoils, effecting the tilting of the body necessary in bottom feeding and counteracting the lifting force of the enlarged anal.

Cyprinodontiadae

In typical cyprinodonts, the head is flattened anteriorly and the mouth opens dorsally, both adaptations for surface feeding (Hubbs and Lagler, 1958).

Banded killifish

In *Fundulus diaphanus* the mouth aperture is relatively narrow, 3.9 mm (6% S.L.) in fish of 60–65 mm S.L. From the side, the jaw angle forms a shallow indentation. The mouth is sub-tubular, the premaxilla being protrusible. The marginal dentition consists of two rows of long, sharp, conical, and recurved teeth.

This species is a most versatile feeder. Small individuals of 30–40 mm total length take mostly chironomid larvae (up to 60% volume), Ostracoda (35%), Cladocera (25%), Copepoda (30%), Amphipoda (5%), and flying insects (5%). In adults of 60–80 mm these same items predominate but small, newly hatched Odonata and Ephemeroptera nymphs, Mollusca, and Turbelaria are also taken. This is the only species to prey upon ostracods to a significant degree. The diet in Fish Lake is similarly diverse. *Fundulus diaphanus*, accordingly, feeds effectively at all levels despite the dorso-terminal position of its mouth. However, when the mouth is fully open its position becomes almost terminal. The body is rounded fusiform, having a height:width ratio of 1.3. The caudal peduncle is moderately long and slender and the pectorals and pelvics are well separated. The pectoral fins are low and spatulate. The dorsal is single, medium-based, of intermediate height, and centrally placed on the body, and the anal is short-based, rectangular, and of intermediate depth. With the exception of the truncate caudal, the body and fin forms are thus

not unlike those of *P. notatus*. The rather long caudal peduncle, however, may serve to compensate for the absence of a forked tail.

Feeding in *F. diaphanus* is as a member of a school. Although the schools are mobile they keep largely to shallow areas of sandy bottom. Individually, the species is characterized by swift darting and evasive movements and moderate maneuverability. It lacks, however, the continuous twisting and turning of *N. heterodon* and *N. crysoleucas* and since it only takes Cladocera at times of superabundance, it is possibly a much less efficient hunter of these organisms. Its ability to handle hard-bodied items is favoured by the marginal teeth. To sum up, *F. diaphanus* may be classified as a species that is rather generalized in body form as well as food and feeding habits.

Fundulus diaphanus frequently rests in the middle water or near the surface. Position is maintained during this time by a continuing series of sharp, rapid beats of the pectorals (synchonously or independently), and sharp flicking movements of the distal portion of the caudal fin. There is little movement in the extended dorsals and anals at this time.

PERCIDAE

YELLOW PERCH

In *Perca flavescens*, the mouth aperture is of moderate width, averaging 16.0 mm (8% S.L.) in fish of 200–250 mm S.L. The mouth is terminal, and from the side, the jaw angle forms an indentation of intermediate depth. The bones of the jaw margin are stout, but the premaxilla is somewhat protrusible. The jaw action can be described as a snapping scoop. The marginal teeth, set in three or four rows, are stout, sharp, conical, straight, and angled posteriorly.

After an initial stage of feeding on Cladocera, Ostracoda, and chironomid larvae, *P. flavescens* passes, by the end of the first year, to a mixed diet of Odonata nymphs (up to 40% volume in some months), Ephemeroptera (30%), newly hatched Mollusca (35%), Ostracoda (30%), chironomid larvae (20%), and fish fry (30%). Thereafter, there is a steady transition to the adult diet which, in fish of over 150 mm total length, is made up of Decapoda (up to 70% in some months), small fish (75%), and Odonata nymphs (40%). The diet in Lake Opinicon corresponds to that recorded for other parts of the range (Nurnberger, 1930; Ewers and Boesel, 1935; Langford and Martin, 1940; Parsons, 1950; Pycha and Smith, 1954). The species thus is a middle-water and bottom feeder. The prevalence of relatively large and hard-bodied items accords well with the general jaw structure and dentition.

The height:width ratio of the body is 1.6, so that it is compressed fusiform. The pectoral–pelvic distance is relatively short, as in all percoids, and the caudal peduncle is moderately long. The pectorals are low and rounded. The dorsal, long-based and of intermediate height, is double, being composed of separate anterior spiny-rayed and posterior soft-rayed segments, as in other percids. The anal is short-based, rectangular, and of intermediate depth. The caudal fin is shallowly forked.

In the aquarium this is a somewhat restless species, never remaining still for long, and preferring to patrol in the lower parts of the tank. Such a hunting pattern must favour the catching of decapods and Odonata nymphs since these organisms have a patchy distribution. Patrolling is a prerequisite also for the piscivorous way of life, although fish do not become important in the diet until *P. flavescens* is large.

When hanging in mid-water, which it does from time to time, *P. flavescens* holds its pectoral fins outwards, almost at right angles from the body. They beat alternately with an oar-like action and a degree of "wrist" movement reminiscent of the sunfishes. Simultaneous movements of the upper regions of the dorsal and caudal fins, characteristic of many other fishes, are lacking. The shallowness of the pectoral beat of *P. flavescens*, terminated before the fin reaches the body, may partly compensate for this. *P. flavescens* sometimes rests on the bottom.

LOG PERCH

In *Percina caprodes*, the mouth aperture is narrow, averaging 4.5 mm (5% S.L.) in large individuals of 80–100 mm S.L. The mouth is ventro-terminal. The jaw angle forms a shallow indentation from the side and the premaxilla is fixed. The marginal teeth are proportionately shorter and more numerous than in *P. flavescens*. The mouth closes with a snapping action. *Percina caprodes* has a rounded knob on the snout that it uses to roll over leaves and small stones to expose the organisms underneath and is the only species in the lake with this feature.

Young *P. caprodes* feed partly on Cladocera (Ewers and Boesel, 1935; Turner, 1921). The adults in Lake Opinicon take a variety of bottom organisms: chironomid larvae (70% volume in some months), Amphipoda (up to 40%), Isopoda (20%), small Anisoptera nymphs (15%), and Ephemeroptera nymphs (10%). This accords with the food in other regions (e.g. Pearse, 1916). The position, diameter, and structure of the mouth correlates well with a diet of exclusively bottom-dwelling organisms of small size.

The body has a height: width ratio of 1.2 and can be described as elongate tubular. It is thus a typical member of the Etheostomatinae which, with the partial exception of the piscivorous Luciopercinae, are the longest-bodied members of the Percoidea. The caudal fin of *P. caprodes* is shallowly forked. The median fins resemble those of *P. flavescens* though the anal, which functions as a prop, is rounded. As in all percoids the pectoral and pelvic fins lie close together, the distance between the two being only 3% of the standard length. This condition is anomalous for a long-bodied fish; compare (Table I) with *Labidesthes sicculus* (16%), *E. lucius* (25%), and *Ictalurus nebulosus* (23%). The pectoral fins are low on the body, exaggerated in size, spatulate or fan-shaped, and are reinforced anteriorly with stout spiny rays. When moving rapidly, these fins sweep the water with synchronized oar-like action. When resting on the bottom, in which position *P. caprodes* spends most of its time,

the laterally projecting pectorals, along with the median pelvics, function as angular supports.

Percina caprodes is incapable of prolonged swimming. Its movements are rapid and erratic, amounting to a jerky zig-zag action. After a short period of violent activity, the fish drops back to the bottom, unable to maintain a position in midwater. This instability probably results from the positions of the paired fins, together with the tubular body form. A tubular body, as compared with a fusiform, does not, however, necessarily prevent its possessor from being an active swimmer (*E. lucius* and *Labidesthes sicculus* are examples). The perciform paired fin distribution has, however, probably determined the direction that evolution could take. The body form and enlarged pectorals are possibly secondary developments. The outcome is a successful evolutionary line of bottom dwellers lacking sustained swimming and directional ability but with well-developed ventral supports for resting, and a powerful muscular body permitting sudden escape movements from this position. The enlarged pectoral fins lack the refined "wrist-action" movements of *P. flavescens*.

Such feeding as has been observed in *P. caprodes* has consisted of a series of short, forward searching movements with intervening rests on the bottom. When a prey item is sighted, it is secured by a sudden dart forward. A leaf or stone is turned over in the same way, the fish pausing an inch or two distant, then quickly pushing the object out of the way.

In Lake Opinicon *P. caprodes* has a very restricted distribution, being confined to areas of pebbly bottom.

Centrarchidae

In the centrarchids, the body form ranges from compressed fusiform to gibbose. The pectoral and pelvic fins lie close together and are lateral. The caudal peduncle is functionally short (though at least 34% of the body length) because the gibbose body trend involves an expansion posteriorly to include much of it. Because of the method of measurement used (anus to end of spinal column), however, it appears long. The centrarchids have a long-based dorsal of intermediate height made up of anterior spiny-rayed and posterior soft-rayed portions. The two are separated in *M. salmoides*. The anal, which also has these subdivisions, varies from a short-based, rectangular structure in this species, through intermediate types in *L. macrochirus* and *A. rupesrtis*, to a long-based fin with greatly expanded posterior lobe in *P. nigromaculatus*. The caudal fin is large and tends to be emarginate.

LARGEMOUTH BASS

In *M. salmoides*, the mouth aperture is exceptionally wide, averaging 50–85 mm (16% S.L.) in fish of 400–600 mm S.L. From the side, the jaw angle forms a deep indentation. The jaw margin is strong, with little protrusibility of the premaxilla. The marginal dentition consists of four to five rows of sharp, conical, and backwardly directed teeth, with those of the anterior row considerably enlarged. In opening, the lower jaw swings well forward and downward to form a snapping scoop.

Micropterus salmoides passes through the Cladocera- and insect-eating stages in the first month or two of life, with fish-eating commencing at about 50 mm total length (Turner and Kraatz, 1920; Ewers and Boesel, 1935; Cooper, 1937). Changes in food with growth in Lake Opinicon have been discussed by Keast (1965). Fish of 30–50 mm total length have a diverse diet of Cladocera (up to 50% volume), newly hatched Ephemeroptera nymphs (60%), Amphipoda (25%), chironomid larvae (20%), along with small quantities of Hemiptera, Copepoda, and Trichoptera nymphs. Slightly larger fish (50–70 mm) feed predominantly on Ephemeroptera nymphs (up to 40%), Odonata nymphs (20%), crayfish (20%), plus smaller quantities of Amphipoda, chironomid larvae, and small fish. Fish above 80 mm are predominantly piscivorous, small fish accounting for between 50% and 90% of stomach volumes and crayfishes for the remainder. At first the chief prey are minnows (*P. notatus* and *N. crysoleucas*), smaller *M. salmoides*, and *L. sicculus* (Keast, 1965). Sunfishes (*L. machrochirus*) and crayfishes form the bulk of the diet of the largest fish (Gilbert, 1962).

The body has a height:width ratio of 2.1 and hence approaches the compressed fusiform type. The separation of the two parts of the dorsal fin permits them to function independently. Thus, when the fish is moving forward, the anterior segment can be seen to lie flat against the back, reducing friction; during turns, however, it is erected (see introductory section for significance).

Adult *M. salmoides* are widely ranging in Lake Opinicon, tagged bass having been recovered 3½ miles away after a lapse of 6 weeks (Curran et al., 1947). First year individuals, however, are largely local in the shallows. In aquaria they spend much of their time patrolling slowly or hanging in midwater. The species obviously has not the maneuverability of the cyprinids.

Micropterus salmoides maneuvers into a favourable position close to its prey before striking. During this time the pectorals beat alternately in a horizontal plane, with only a hint of the "wrist action" seen in *L. macrochirus*, additional stability being obtained from terminal movements in the soft-rayed portion of the dorsal fin and upper lobe of the caudal fin. *Micropterus salmoides* is well adapted for the piscivorous way of life, particularly in mouth form.

SUNFISH

In *Lepomis macrochirus*, the mouth aperture is relatively narrow, averaging 8.0 mm (6% S.L.) in fish measuring 125–150 mm S.L. This is about one-third that of *M. salmoides* and half that of *A. rupestris*. From the side, the jaw angle forms a shallow indentation. The premaxilla is relatively protrusible, accounting for the rather tubular form of the terminal mouth. The marginal teeth resemble those of *M. salmoides* but are smaller. Food is obtained by a sharp snapping of the jaws possibly supplemented sometimes by a sucking action.

This fish is by far the most generalized feeder in Lake Opinicon, up to nine types of organisms commonly being found in a stomach at the 5% volume level or over (Keast, 1965). The different year classes consume the same foods,

only the proportions varying. The major foods are chironomid larvae (up to 50% volume), Cladocera (30%), Amphipoda and Isopoda (10%), flying insects (35%), Odonata nymphs (20%), Ephemeroptera nymphs (10%), Trichoptera larvae (15%), Mollusca (15%), and fish fry (10%). Small quantities of Ostracoda, Copepoda, and algae, are also commonly present. Such diversity also characterizes other parts of the range (Moffett and Hunt, 1945; Ball, 1948; and Gerking, 1962). There is a large element of opportunism in the feeding of *L. macrochirus*, the dominant food usually being the resource that is most abundant at the time. *Lepomis macrochirus* feeds at all levels in the water.

The body form is gibbose, with the height:width ratio 2.5. Like other species with this body type, *L. macrochirus* feeds by patrolling slowly or by hanging still in the middle water from which position it can readily rush to the surface or bottom. In the lake individuals hover a few feet apart, moving independently in search of food.

The structural attributes and fin movements are directly associated with hanging, or hovering, in the water (see previous discussion). Stability is achieved by undulations of the enlarged posterior lobes of the dorsal and anal fins and the upper lobe of the caudal fin. The large, graceful pectoral fins, by which maneuvering is accomplished, beat independently with a pronounced rotating or "wrist" action. Their falcate shape is probably associated with reducing water resistance on the recovery stroke.

Lepomis macrochirus is local in its distribution and individual fish can be observed in the same place for hours on end.

ROCK BASS

In *Ambloplites rupestris*, the mouth aperture is wide, averaging 16.0 mm (12% S.L.) in fish of 130–150 mm S.L. The form of the mouth and the dentition are similar to those of *M. salmoides* and the jaw margins are thick. The jaw angle, however, forms a moderate rather than a deep indentation. In Lake Opinicon fish up to 70 mm total length feed mainly on chironomid larvae (up to 50% volume), Ephemeroptera nymphs (35%), Odonata nymphs (30%), Cladocera (40%), Amphipoda (30%), Isopoda (15%), and surface insects (35%), along with small quantities of Copepoda and Hydracarina (Keast, 1965). Above 75 mm there is an abrupt shift in diet, Odonata nymphs (up to 75% volume), Ephemeroptera (35%), Trichoptera (35%), fish fry (30%), and crayfish (15% and over), making up the bulk of the food. Chironomid larvae, Amphipoda, and Isopoda are relatively unimportant. The larger *A. rupestris* (i.e. between 120 and 200 mm) subsist almost entirely on crayfish and Anisoptera nymphs.

Hence, in its diet, *A. rupestris* specializes on the larger bottom-dwelling insects. The correlation between this and the relatively strong mouth and moderate gape is obvious.

The body form is intermediate between those of *M. salmoides* and *L. macrochirus*, i.e. sub-gibbose, being relatively thick, and having a height:width ratio of 2.1. It cruises more than the latter, and shows more tendency to move

from the deeper water into the shallows to feed at night. Nevertheless, the "hanging and rushing" habit is well-developed, although the pectoral fins are distinctly shorter and more rounded and show only slight wrist action compared with those of *L. macrochirus*. Despite the fact that minnows appear in the diet of the larger fish, aquarium tests show *A. rupestris* to be much less adapt at catching these than *M. salmoides*, having great difficulty securing them if the first strike is unsuccessful. Tadpoles, by contrast, present no problem.

BLACK CRAPPIE

In *Pomoxis nigromaculatus*, the mouth aperture is moderate, averaging 14 mm (9% S.L.) in 130–180 mm S.L. fish. From the side, the jaw angle forms a shallow indentation. The premaxilla is somewhat protrusible and the lower jaw swings well forward on opening. The marginal dentition is similar to that of the other centrarchids, but the jaws are structurally lighter than in either *M. salmoides* or *A. rupestris*.

The main foods in Lake Opinicon are *Chaoborus* larvae (up to 70% of stomach volumes), Cladocera (up to 50%), Copepoda (20%), fish fry (25%), flying insects (15%), chironomid pupae and larvae (25%), and Ephemeroptera nymphs (10%). These items characterize all age groups, the proportions alone changing. It is apparent that, although the species is predominantly a midwater feeder, some prey is taken at all levels. The numerous gill rakers of *P. nigromaculatus*, 26–30 on the first arch (Keast, unpublished data) account for the prominence of Cladocera in the diet. The food in Lake Opinicon accords with that from other parts of the species range (Forbes, 1878; Forbes and Richardson, 1920; Pearse, 1919; Bailey and Harrison, 1945; Mitchell, 1945, 1949). In Texas, Mitchell (1945) has noted that planktonic Crustacea make up 50% of the diet until a total body length of 180 mm is reached. The species subsists largely on small fish after it has reached 250 mm total length.

The body and head are narrower than those of *L. macrochirus*, the height: width ratio being 2.8, and associated with this the long-based dorsal and anal fins are larger, with greatly expanded posterior lobes. The pectorals are large and rounded. The swimming and general hunting actions are not unlike those of *L. macrochirus*, with the addition of plankton straining. The species inhabits the deeper waters in the lake and is more mobile. There is some movement into the shallows at night.

ATHERINIDAE

BROOK SILVERSIDE

Labidesthes sicculus, a small fish, has a flat head that is modified anteriorly into a beaked snout. The mouth is dorso-terminal and from the side the jaw angle forms a deep indentation. The premaxilla is moderately protrusible. The mouth aperture is narrow, averaging 3.2 mm (5% S.L.). The well-developed marginal dentition consists of three rows of long, slender, sharp, conical, and slightly recurved teeth. These probably function like the serrations on

a pair of tweezers ensuring a good grip on flying insects seized at the surface. The mouth operates with a snapping action.

Labidesthes sicculus is a specialized feeder, the diet being made up of Cladocera (frequently up to 80% volume), small flying insects (up to 40%), and *Chaoborus* larvae (50%). Smaller individuals in the population take relatively greater amounts of Cladocera (Keast, 1965). Hubbs (1921) and Boesel (1938) also record that Cladocera and flying insects predominate in the diet. All the food, accordingly, is taken from the middle water or surface. *Labidesthes sicculus* may leap out of the water to catch hovering insects (Hubbs, 1921).

The elongate tubular body, not unlike that of a pike, has a height:width ratio of 1.3. Obvious adaptations for surface feeding are the almost straight dorsal body line, the small dorsal fin, and the compensatory long-based deep, triangular, and markedly enlarged anal fin. The pectorals are set very high on the body, a position reminiscent of the marine "surface-skipping needle fish" (*Tylosurus*). When *L. sicculus* is holding still in the water, or is swimming slowly, the pectorals move independently with wide upsweeping movements. The species is highly mobile, ranging widely over the lake. It is apparently pelagic in midsummer, as in Lake Erie (Hubbs, 1921). Both nocturnal and diurnal feeding were observed.

STRUCTURAL SPECIALIZATIONS, WAY OF LIFE, AND FOOD NICHE

The survey shows that each of the structures studied is subject to variation from one species to another, and most of the differences may be quantified.

No two species are identical in all their characteristics. The structures (Table II) include a series of distinctive body forms, fin features, types of movement, mouth positions and shapes, and these can be correlated with different ways of life, degree of maneuverability, swimming power and speed, feeding levels, and kind of foods eaten. Some specializations characterize all the members of a family studied but others apply only to genera and species.

Ultimately, the structural characteristics of species are related to their food niches. The major types of food available in the lake, and the characteristics of the species that utilize them may be summarized as follows.

(*a*) *Large-bodied Invertebrates.* Odonata and Ephemeroptera nymphs, and Decapoda are important foods of *A. rupestris* and *P. flavescens.* The piscivorous *M. salmoides*, above 80 mm in length, take many Decapoda. These are all large fish, and have compressed fusiform to sub-gibbose bodies (Table II) and shallowly forked tails (Fig. 3) and are somewhat widely ranging. All have terminal, scoop-like mouths (Fig. 4), moderate to wide mouth apertures, strong jaws, and numerous marginal teeth.

(*b*) *Small-bodied Invertebrates.* The fish feeding on these organisms range from small *U. limi*, with its somewhat strong, terminal, scoop-like mouth, to the large-bodied, wide-mouthed *I. nebulosus*, and *P. caprodes* with a small, ventro-terminal mouth. As noted, however, the feeding habits of

the three differ considerably. *Umbra limi* takes many hard-bodied insects whereas *P. caprodes* seeks mainly chironomid larvae and amphipods. *Ictalurus nebulosus* depends on chemosensory barbels to locate prey, and its bottom feeding undoubtedly partly entails mouthing, or sifting, prey items from the mud. *Umbra limi* and *P. caprodes* are not strong swimmers. Small-bodied invertebrates, as a food type, obviously lend themselves to predation by fishes of relatively local habits.

(*c*) *Bottom Ooze.* The mouth of *P. notatus* is clearly adapted for this food. The species has a less maneuverable body than the other cyprinids.

(*d*) *Plankton. Notemigonus crysoleucas* and *N. heterodon* have compressed fusiform bodies and a range of other features conferring considerable mobility and maneuverability. These are obviously essential for the pursuit and capture of individual plankters. *Pomoxis nigromaculatus*, a gibbose "water-hanger", obtains them, however, by means of its gill raker screen. *Labidesthes sicculus*, a small fish with a tubular body also takes planktonic organisms individually; *Chaoborus* larvae replace them as the major food seasonally and when the fish increase in size.

(*e*) *Surface Insects.* The species to which surface insects are important are *L. sicculus*, *N. crysoleucas*, *N. heterodon* and, to a minor extent, *F. diaphanus* and *P. nigromaculatus*. All have dorso-terminal mouths. *Labidesthes sicculus* is far the best adapted structurally both in body and mouth form. *Fundulus diaphanus* and *N. crysoleucas*, which have curved backs have to swim at a shallow angle to the surface, in contrast to *L. sicculus*.

(*f*) *Fish. Esox lucius* and *M. salmoides* show a wide range of structural specializations for the piscivorous way of life. They reach the largest size, have stable fusiform or tubular bodies, narrow caudal peduncles of short or medium length, forked tails, and efficient propulsive surfaces. They are adapted for prolonged cruising and for making quick rushes. The mouth opening is wide, the jaws strong, and the teeth large.

Perca flavescens, it might be noted, has a body form convergent with that of *M. salmoides* (Fig. 3). The mouth width, however, is only 8%, instead of 16% of the standard length, restricting the size of food that can be handled and limiting its piscivorous activities until it reaches a large size.

(*g*) *Generalized feeders. Lepomis gibbose*, *L. macrochirus*, and *F. diaphanus* are by far the most diverse and versatile feeders in the lake, taking a wide range of foods and feeding at all levels in the water. The two are highly different in most of their bodily attributes (Table II, Fig. 3), and in their hunting habits. *Lepomis macrochirus* uses its "water-hanging" ability to place it in a favorable position to rush items on the bottom, surface, or middle water, as these appear. *Fundulus diaphanus*, a small, maneuverable species, patrols the shallows in schools. Since both species have relatively small mouths there is an upper limit to the size of organisms that can be handled.

It is obvious from the above survey that, apart from the many clear-cut correlations between form and way of life the species composing the Lake

Opinicon fauna show several instances of alternative structures serving to fill common ends.

CHANGING FOOD NICHE AND STRUCTURE WITH GROWTH

Many fish change diet as they grow. Instances of this in the present fauna have been given by Keast (1965). The correlation between changes in body form and ecology has been little studied except by Nikolsky (1963, fig. 84) in the cyprinid, *Rutilus rutilus caspicus*. The subject lies beyond the scope of the present paper, but some general comments may be made at this stage with respect to the Lake Opinicon fishes.

There is no case, in the present fauna, of a structure being significant at one growth stage but not another. However, increasing body size and mouth aperture width do permit a change in "food niche" and way of life. *Amblop-lites rupestris*, for example, changes from chironomid larvae and other small items to Odonata and Ephemeroptera nymphs between body lengths of 75 and 100 mm, and later to crayfish (Keast, 1965). The widespread use of Cladocera by fry and fingerlings of virtually all species is obviously associated with the ability to pursue and catch these small items.

One other aspect of ecological change with growth has been commented upon previously (Keast, 1965), that being the habit of first year *M. salmoides* and *A. rupestris* of keeping to the shallows, a habitat different from that occupied by the adults. Avoidance of predation is presumably the main reason for this but, structurally speaking, they could equally be said to be limited to this habitat by their relative slowness and inability to range widely and to handle the larger kinds of food available in the adult habitat.

STRUCTURE AND THE REDUCTION OF INTERSPECIFIC COMPETITION

The present study shows clearly that whereas structure does not prevent food overlaps in cohabiting species, it does serve to reduce interspecific competition because most species have specializations that place them at an advantage in certain situations, or in the obtaining of certain foods. Beyond this, it is a fair generalization to say that the greater the number of structural specializations, the more the species niche tends to be circumscribed.

Some of the best examples in the lake of structural specializations reducing interspecific competition are as follows.

(*a*) The extreme maneuverability of the body in the cyprinids *N. crysoleucas* and *N. heterodon* permits them to be specialized plankton feeders. Significantly they, unlike most of the other species, are able to obtain this resource even when it is rare. Competition between these two species is partly avoided by spatial separation and different behavioral patterns.

(*b*) *Labidesthes sicculus* has a range of structures permitting it to catch insects hovering over the surface, which the other species apparently cannot do. The cyprinids lack the extreme specializations for surface living:

the straight dorsal line, flattened, beak-like snout, and well-developed rows of marginal teeth.

(*c*) As noted, *A. rupestris*, *M. salmoides*, and *P. flavescens*, living on hard-bodied invertebrates, have relatively strong mouths. Although these are not identical in form (that of *P. flavescens* is smaller), ecological exclusion is enhanced by *P. flavescens* concentrating mainly on Zygoptera, and *A. rupestris* on Anisoptera nymphs (Keast, 1965). *Micropterus salmoides* more than 80 mm long are predominantly piscivorous.

(*d*) The small *U. limi* is adapted by its body form for life in weedy shallows and by its mouth for taking hard-bodied insects; the differences in habitat, structure, and food between this species and the cyprinids are marked. The marginal teeth of *U. limi* plus *F. diaphanus* and *L. sicculus* are undoubtedly of value in seizing and holding hard-bodied prey.

(*e*) The ventrally-placed, tubular mouth of *P. notatus* is an adaptation for bottom-ooze feeding. There is no question of competition here as it is the only fish in the fauna to utilize this resource.

(*f*) *Percina caprodes*, by means of its leaf- and stone-turning habits, is able to obtain foods not available to other species.

(*g*) *Ictalurus nebulosus* is unique in Lake Opinicon in body form and feeding habits. This nocturnal chemosensory bottom-feeder frequents somewhat deep waters, where it can obtain chironomid larvae much more effectively than other species relying on vision. It also has the habit of submerging itself in, and wriggling freely through, the ooze at the bottom of ponds (Loeb, 1964). It would seem likely that buried food may be obtained from the mud at this time.

(*h*) The piscivorous *E. lucius* and *M. salmoides* are structurally adapted for their role by a wide range of features. *Esox lucius* is the more specialized piscivore structurally and it lives almost entirely on fish beyond a size of 60 mm. Adult *M. salmoides*, by contrast, combine fish and decapod eating. *Esox lucius* can, apparently also feed at lower temperatures than *M. salmoides*, and the midsummer period of reduced feeding is less marked in the latter.

Although *E. lucius* and *M. salmoides* are well-armed with marginal teeth, and these are characteristic of piscivores generally, their absence is apparently not a barrier to the development of a fish eater; the piscivorous minnow *Ptychocheilus*, a west coast cyprinid, is an example.

The above examples emphasize that structure plays a basic role in channelling species into particular ways of life and feeding niches. Of equal importance in limiting interspecific competition, however, are the obvious limitations imposed by body size, poor swimming ability, type of mouth, and other factors.

Several important conclusions emerge from the present study and its predecessor (Keast, 1965). A clear degree of specialization in feeding structures, feeding behavior, habitat, and actual food consumed is indicated. This is in conflict with the statement of Forbes (1914) that fish have a common body of food resources which many of them draw upon according to the

circumstances, and with the findings of Hartley (1948) that, in the Cam River in England, the members of the fish community were distinguished by no more than the varying proportions they drew from a common stock of food. These general conclusions of Forbes and Hartley are accepted by Larkin (1956), who quotes various studies in support. The difference in findings of the present works, relative to previous works, is significant. The explanation presumably lies in the superficial nature of most fish food studies, the majority of which have been based on limited series collected at irregular intervals, with little attempt to simultaneously study the food organisms in the environment or to take structure into account. Habitat specializations have not been given the degree of importance they merit, although various workers have discussed them; for example, Hile and Juday (1941) respecting certain Wisconsin lakes and Fryer (1959b) relative to Lake Nyassa.

Habitat and body form are, of course, interrelated; for example, fishes with gibbose bodies can only occur under conditions of relatively still water; riffle species and pelagic species have a readily identifiable shape. In a small lake, series of species are not separated into distinctive sub-faunas on the basis of habitat. Minor habitat differences do, however, separate individual species spatially. As noted in Keast (1965), *P. nigromaculatus* and *P. flavescens* are inhabitants of the deeper water, *L. macrochirus* and *F. diaphanus* the shallows. Thus, when the two are feeding on Cladocera, these organisms are, in part, being taken from different areas. The same applies to feeding on chironomid larvae by *F. diaphanus*, *P. caprodes*, and *I. nebulosus*, which live mainly over sandy shallows, areas of pebbly bottom, and in deeper sections of the lake, respectively. Interspecific competition cannot, of course, be defined on trophic relationships alone: Densities, spawning times, growth rates, capacity to withstand winter temperatures and low oxygen tensions, and ability to do without food for long periods, must be recognized as adaptive specializations.

A significant feature of the structural differences separating the Lake Opinicon fishes is that in few cases are specializations so extreme as to prohibit the owner from taking at least three distinct kinds of food. This flexibility reflects the environment, for it is obviously advantageous for all species to be able to take advantage of temporarily superabuntant resources. Cold temperate waterways, with their somewhat unpredictable temperature regimes, must favour retention of generalized features. This contrasts with certain tropical situations where species show a variety of bizarre tooth types and body forms, and true herbivores are well developed (Norman and Greenwood, 1963; Fryer, 1959a). The differences between the African Rift Lakes and the Great Lakes could, of course, in part be due to the greater age of the former.

The final conclusion from the present study is that a great deal can be predicated about the ecology of freshwater fish species from a study of body morphology. The situation is, then, similar to that in birds even though a great deal remains to be learnt of the significance of finer structural details.

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Comparative Limnology of Lakes in the Southern Rocky Mountain Trench, British Columbia[1,2]

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ABSTRACT

Within a restricted geographical area of British Columbia, detailed examination in 1960 and 1961 of nine lakes having similar morphometric and climatic characteristics but exhibiting a wide range in dissolved nutrients (50 to 1463 ppm) suggested that standing crops of plankton were related to oxygen deficits and perimeter-to-area ratios of the lakes. Total dissolved solid contents of the lakes were not closely correlated to standing crops of plankton, bottom fauna, or fish. Ranking by selected physical or chemical indices of productivity failed to agree with ranking based on standing crops or various biological measurements of productivity. Water level fluctuation, perimeter-to-area ratios, lake basin shape, and the size and nature of the drainage area are discussed as some of the possible factors which interact to modify the expression of the primary factors in productivity.

INTRODUCTION

The purpose of this study was to examine in detail nine lakes all located within the southern Rocky Mountain Trench and having a wide dissolved nutrient range (50 to 1463 ppm), and to evaluate the importance of total dissolved solids (TDS) in determining standing crop levels in lakes where variation in climatic and morphometric factors modifying these levels was minimal.

Northcote and Larkin (1956) found TDS the best single indicator of standing crops of plankton, bottom fauna, and fish in 100 lakes exhibiting a wide range of TDS throughout British Columbia. However, for 33 lakes within the Southern Interior Plateau region of the province, total dissolved solids (ranging between 85 and 558 ppm) showed no significant relationship with standing crops of organisms (Larkin and Northcote, 1958). Thus, although total dissolved solid content of lake waters apparently was related to standing crop levels over the whole province, no such relationship was apparent in lakes exhibiting a fairly broad range in TDS but within a restricted geographic area.

METHODS

Lake volumes were calculated from soundings by the formula $V = \frac{h}{2}(A_1 + A_2)$ in which h is the vertical depth of each stratum, and A_1 and A_2 are

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the areas of the upper and lower surfaces of the stratum whose volume is to be determined. Other parameters of lake morphometry, with the exception of perimeter-to-area ratios (Rawson, 1960), were calculated as suggested by Welch (1948). Most limnological measurements were made from a selected deep water station during the five or six sample periods in 1960 and 1961.

Transparency of lake water was measured with a 20-cm diameter Secchi disk on the shaded side of the boat.

Water samples for analysis of dissolved oxygen by the unmodified Winkler technique were obtained with a 1200-cc Kemmerer water bottle. The sampler had been in use for several years but had not been coated to prevent contact of water with the metal. No adjustment was made in titration values to account for reagent volumes except for those used in calculating gross primary productivity.

Oxygen deficits in the hypolimnion were calculated for all lakes except Horseshoe, which was omitted because of water level fluctuation at the time of summer temperature stratification. Oxygen values were taken during the summer stagnation period, from July 25 to August 11. The values were compared with those observed during the ice breakup in the following spring, the differences being taken as the oxygen deficits.

Temperatures were obtained with a Yellow-Springs thermistor thermometer, model 43TB, which had been standardized with a long stem mercury thermometer calibrated to 0.1 C.

A Wisconsin plankton net with a diameter of 11.2 cm was used until March 1961, after which a 25-cm net of similar type was employed. Both nets were fitted with No. 10 silk having 109 meshes per linear inch. Three total vertical plankton hauls were taken at a deep water station each time a lake was sampled. Net plankton volumes were determined after a 24-hr settling period in 15-cc centrifuge tubes. Two plankton samples from triplicate vertical hauls were dried in an oven at 60 C for 48 hr or until constant weight was obtained. Weights were determined using a Mettler model K7 analytical balance.

Bottom fauna samples from a 6-inch Ekman dredge were washed using a screen with 30 meshes per linear inch and sorted on a white tray while the organisms were alive. The total number of dredgings in each lake ranged from 22 to 42 for the five sample periods.

Standard sets of braided nylon experimental gill nets of 1- to 3½-inch stretched mesh, at ½-inch intervals, were used for fish sampling. Nets were set at selected shoal areas for a 12-hr period during the night.

A sediment trap, following the design of Patalas (personal communication), consisted of a 24-oz icebox jar suspended at the lower limit of the thermocline for a 10-day period.

Gross primary productivity was estimated using "light" and "dark" bottles suspended at 1, 3, 5, and 7 ft from a weighted wire line attached to a 1 sq ft Styrofoam buoy. Dark bottles were 300-cc BOD bottles made lighttight by covering with black tape and having several coats of black Glyptol paint. One bottle, termed a "blank", was used to determine the dissolved oxygen at

the start of the experiment. Light and dark bottles were suspended for a 12-hr period of daylight between June 27 and July 8, 1961. Titration was done on the same day as the *in situ* oxygen measurements and followed the methods given by Strickland (1960). The photosynthetic quotient was assumed to be 1.2 for productivity calculations.

In primary productivity calculations the dark bottle oxygen concentration exceeded that of the light bottle at certain lake depths (Sparrow, 1993). Dugdale and Wallace (1960) reported similar findings when studying two lakes in Alaska. Where this occurred, the dark and light bottle values were not used for gross primary productivity estimates. Productivity estimates were calculated as the averages of measurements obtained from four lake depths.

The nine lakes were ranked on a scale of 0 to 9 for each factor considered to influence or indicate productivity. For factors directly related to productivity, the lake having the highest value was assigned a rank of 9 and the lake with the lowest value given 0 (Reimers et al., 1955). Lakes with intermediate values were ranked between 0 and 9 in proportion to their absolute values. The mean rank for each lake was the average of the individual ranks for a number of factors (e.g. physical factors). The mean rank is not meant to imply that all factors influence productivity equally, but in the absence of knowledge concerning their individual influences, equal weight was given to each factor.

Low oxygen concentrations in the hypolimnion have been used as an indicator of high productivity in the epilimnion (Hutchinson, 1938). Magnesium and calcium are important in plant and animal ecology (Welch, 1952). In ranking, high silica concentrations were assumed to indicate a potential for productivity; however, low concentrations could indicate high utilization.

DESCRIPTION OF THE STUDY AREA

Figure 1 shows the locations of the nine lakes in the southern Rocky Mountain Trench, British Columbia. Two main mountain ranges, the Rocky Mountains to the east and the Columbia Mountains to the west, delimit the Rocky Mountain Trench. The valley floor varies between 2460 and 2800 ft elevation in the area of study.

Hiawatha, Kiakho, New, and Jim Smith lakes are situated in a formation of argillaceous quartzites and argillites. Calcareous beds are not uncommon and carbonates occur in minor quantities. Lazy Lake is located in an area of sedimentary sand and clay and Horseshoe and Enid lie in areas of stream and glacial deposits where the bedrock remains concealed. A formation of siliceous limestone surrounds Bednorski Lake whereas magnesian limestone and slate surrounds Lillian Lake.

The principal trees in the southern part of the trench are ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and Douglas fir (*Pseudotsuga menziesii*). Lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*) also occur around some of the study lakes.

Hiawatha, New, and Lillian lakes have wooded shorelines whereas Enid and Horseshoe are relatively free of trees about the lake margin. The remaining four lakes have partially treed shorelines and some pasture or grassland borders Jim Smith, Bednorski, and Lazy lakes.

The drainage areas of all but Kiakho Lake were logged 10 to 15 years ago. Within recent years the Kiakho watershed was the site of logging activity.

Temperature and precipitation records are available for one inactive and four active weather stations close to the lakes studied (Fig. 1). In general the area experiences low precipitation, severe winters, and dry summers.

The mean air temperature in August is 16.7 C (62 F) at Cranbrook and 16.1 C (61 F) at Wilmer. In January the mean temperature decreases to –9 C (16 F) at Cranbrook and –10 C (14 F) at Wilmer. The annual precipitation varies from 30.5 to 58.5 cm (12–23 inches) with latitude and altitude, and snow accounts for about 30% of the precipitation. June is on the avarage the wettest month and March or April the driest.

Chapman (1952) states that northwest and southeast winds are dominant in January and July in the northern part of the study area, and south and southwest winds in the south in both seasons. New, Lazy, Jim Smith, and Kiakho lakes would be expected to have the greatest effect from dominant winds because of their orientation. However, Kiakho is protected from excessive winds by surrounding hills. Horseshoe on the other hand is susceptible to wind from any direction.

Physical Characteristics of the Lakes

The nine lakes are similar in many of their morphometric features including maximum depth, mean depth, volume development, and maximum length (Table I). This is especially true when considering the great differences to be found among lakes in British Columbia or even within the Rocky Mountain Trench. Enid and Horseshoe have no surface inlet or outlet streams but Horseshoe has unusually large water level fluctuations during the summer and fall months. Seasonal inlets or outlets or both are found in Hiawatha, Lillian, Jim Smith, and New lakes. Most of the streams have flows of less than 0.014 m^3/sec (0.5 ft^3/sec) but the inlet flow of Lillian is between 0.03 and 0.06 m^3/sec (1 and 2 ft^3/sec). Kiakho, Bednorski, and Lazy lakes have permanent inlet or outlet creeks, which seldom exceed 3, 1, or 0.5 ft^3/sec respectively.

The lakes range in area from 10.1 acres (Hiawatha) to 77.8 acres (Horseshoe). They could be grouped into two sizes: Hiawatha, Bednorski, Kiakho, and, at low water, Horseshoe as the smaller lakes (10–30 acres) and the remainder as the larger group (52–78 acres).

The shoreline development of Hiawatha Lake most closely approximates that of unity. Kiakho shows the greatest departure (2.34) from a circular form. The perimeter-to-area ratio is probably a better criterion than shoreline development when comparing lakes of different areas (Rawson, 1960). The lakes other than Hiawatha and Kiakho have similar ratios.

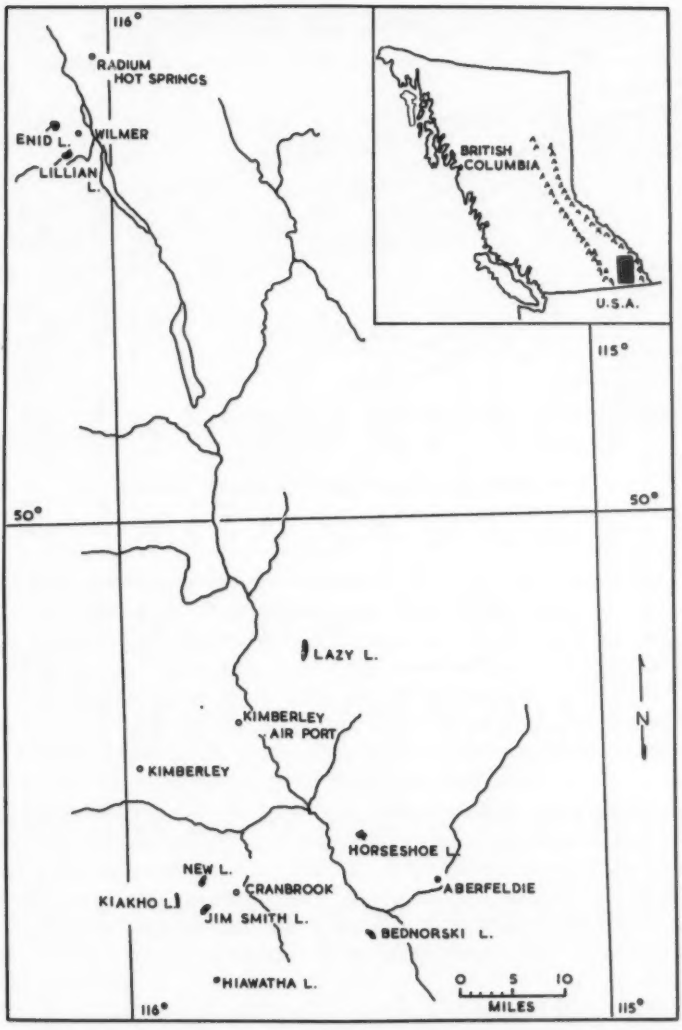

FIG. 1. Locations of the nine study lakes and weather stations within the southern Rocky Mountain Trench of British Columbia.

Hiawatha and, at low water, Horseshoe have mean depths about one-half as great as most of the other lakes, the range for the nine lakes being 8.7 to 27.9 feet.

The hypsographic curves (Fig. 2) show the features of shape of the lakes and their areas at various depths. Bednorski and Jim Smith lakes have 68 and

TABLE I. Morphometric data for nine lakes in the southern Rocky Mountain Trench.

		Hiawatha	Kiakho	Horseshoe		New	Jim Smith	Bednorski	Lazy	Lillian	Enid
Elevation	m	957	1,097	853		1,195	1,058	853	905	942	963
	ft	3,200	3,600	2,799		3,921	3,470	2,757	2,970	3,091	3,160
Surface area	Hectare	4.1	12.1	10.7[a]	31.5	27.6	21.2	9.6	31.4	2.66	22.3
	Acre	10.1	29.9	26.4	77.8	68.3	52.5	23.8	77.6	65.8	55.0
Maximum depth	m	5.2	9.8	6.1[a]	11.6	10.4	7.3	13.1	10.7	11.6	8.2
	ft	17	32	20	38	34	24	43	35	38	27
Mean depth	m	2.6	4.7	2.7[a]		3.4	4.9	8.5	5.2	5.1	4.1
	ft	8.7	15.3	8.8		11.1	16.2	27.9	17.2	16.7	13.5
Volume	$m^3 \times m^5$	1.08	5.65	2.87[a]		9.31	10.53	8.19	16.51	13.57	9.18
	acre–ft	88	458	233		755	854	644	1,338	1,100	744
Maximum length	m	344	1,006	600[a]	1,152	1,052	846	503	1,372	777	701
	ft	1,128	3,300	1,969	3,780	3,450	2,775	1,650	4,500	2,550	2,300
Maximum width	m	168	117	277[a]	503	372	320	226	297	777	594
	ft	552	385	909	1,650	1,220	1,050	742	975	2,550	1,950
Shore development		1.17	2.34	1.20[a]	1.63	1.33	1.43	1.21	1.95	1.76	1.44
Volume development		1.53	1.44	1.32[a]		0.98	2.04	1.95	1.50	1.31	1.50
Perimeter	m	845	288	1,400[a]	3,246	2,487	2,359	1,333	3,886	3,228	2,414
	ft	2,773	9,460	4,594	10,650	8,160	7,740	4,372	12,750	10,590	7,920
$\frac{\text{Perimeter}}{\text{Area}} \times 10^3$		6.28	7.28	3.99[a]	3.14	2.74	3.38	4.22	3.77	3.70	3.31
Drainage area	Hectare	124	777	2,020		202	1,243	4,105	1,362	461	132
	$mile^2$	0.48	3.00	7.80		0.78	4.80	15.85	5.26	1.78	0.51
Water level fluctuation	ft	1.5	1.5	21.0		2.0	2.0	1.0	6.0	1.5	2.0

[a]Low-water data.

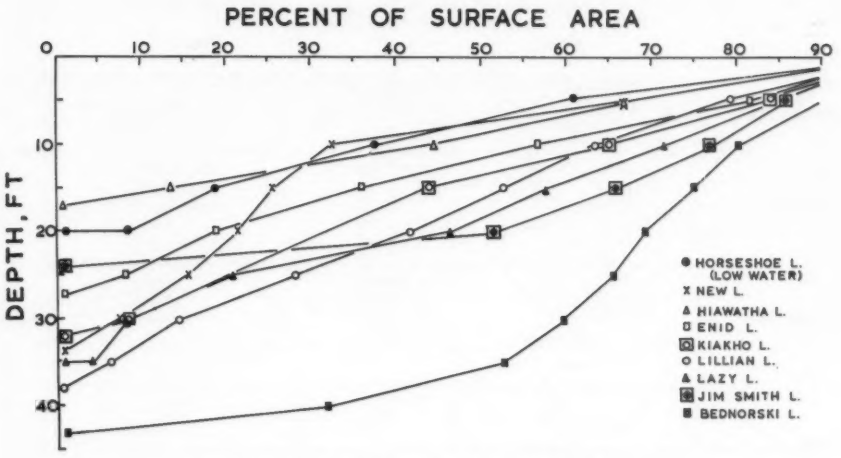

FIG. 2. Hypsographic curves of the nine study lakes.

73% of their surface areas represented at one-half their maximum depths or more; New Lake, 24%; the remaining six lakes, 38 to 53%.

All lakes except Hiawatha had similar surface and bottom temperatures and all, including Hiawatha, exhibited thermocline formation (Fig. 3). In Hiawatha, Kiakho, and Enid lakes, mean epilimnion temperatures in late summer of 1961 were 3.8 to 3.1 C lower than midsummer epilimnion temperatures of 1960 (Table II). A likeness exists among mean epilimnion temperatures except for the high temperatures of Hiawatha and Lazy.

In 1960 the surface and epilimnion temperature of all lakes decreased considerably by mid-September but Bednorski, Lillian, and Enid lakes still showed thermal stratification (Fig. 3). The effects of altitude and latitude were reflected in the growing season of the lakes. Lakes of high elevation and more northerly latitude had later ice removal. Likewise New and Jim Smith as lakes of high elevation had 21–23 inches of ice and low elevation lakes had 8–18 inches of ice.

The greatest transparency was observed in New, Lillian, Lazy, and Jim Smith lakes (Fig. 4). Intermediate in water transparency were Hiawatha, Kiakho, Horseshoe, and Bednorski lakes. Enid was outstanding by having the lowest visibility of all lakes. Little variation in transparency was evident in Enid, Hiawatha, Jim Smith, and Bednorski lakes during the period of measurement.

On the basis of some physical factors reported in the literature as influencing or indicating productivity, the mean ranks exhibit a narrow range of values with the possible exception of Hiawatha Lake (Table III).

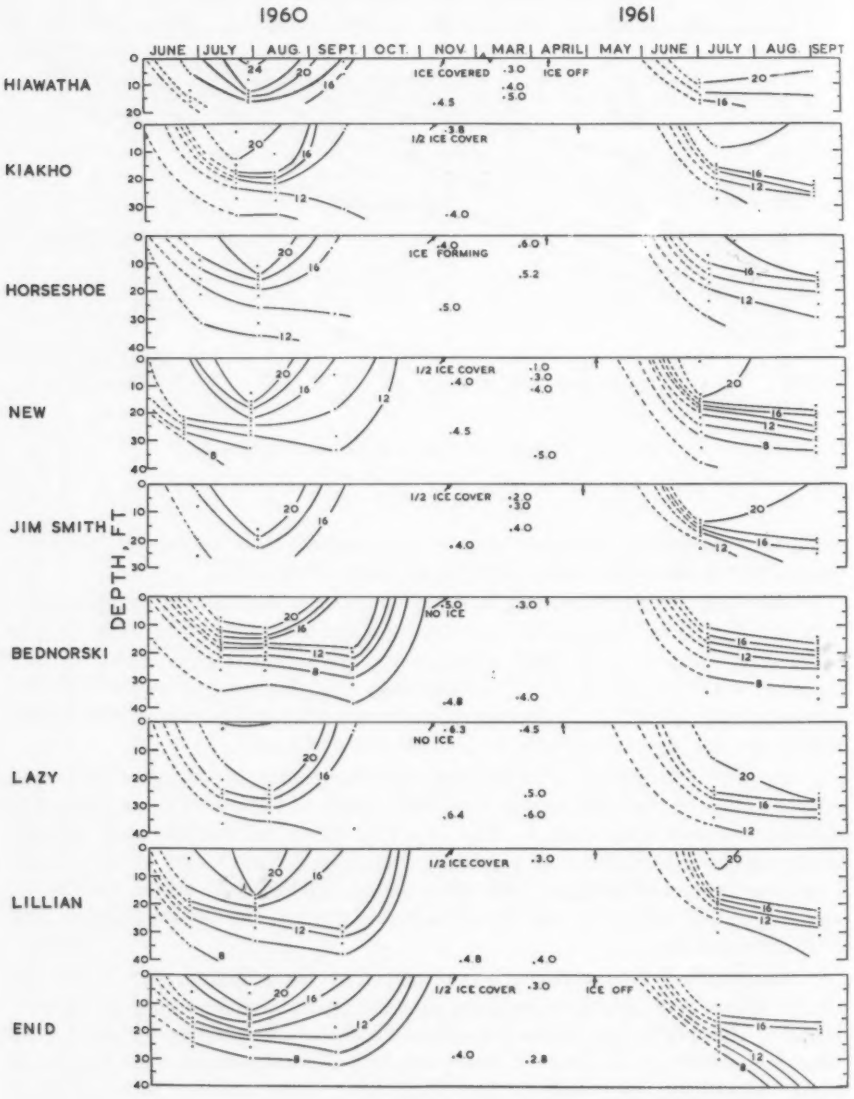

FIG. 3. Seasonal temperature (C) distribution with depth (ft) at one limnology station in each of the nine lakes in 1960 and 1961. Approximate periods of ice cover are indicated.

TABLE II. Mean summer epilimnion temperatures (C) of the nine lakes for 1960 and 1961.

Lake	July 20–August 5, 1960	August 30–September 1, 1961
Hiawatha	23.8	20.0
Kiakho	21.2	17.6
Horseshoe	21.3	20.0
New	21.5	19.4
Jim Smith	21.4	19.9
Bednorski	20.2	19.3
Lazy	21.5	21.3
Lillian	20.6	18.9
Enid	21.4	18.3

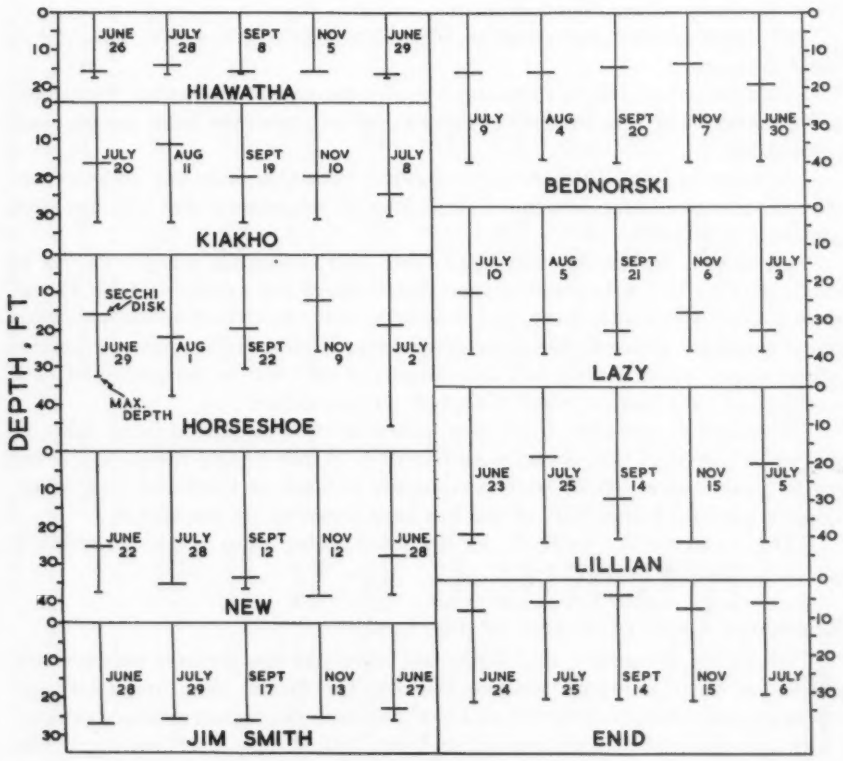

FIG. 4. Transparency in relation to maximum depth (ft) of the nine lakes during 1960 and 1961.

TABLE III. Ranking of the lakes by physical factors.

Lake	Mean depth	Perimeter / area	Mean transparency	Mean epilimnion temperature	Drainage area	Mean rank
Hiawatha	9.0	7.0	5.8	9.0	0	6.2
Kiakho	5.9	9.0	4.8	0	1.5	4.2
Horseshoe	8.9	2.5	5.1	4.3	4.3	5.0
New	7.9	0	0	3.6	0.1	2.3
Jim Smith	5.5	1.3	3.0	4.3	2.5	3.3
Bednorski	0	3.0	5.8	1.1	9.0	3.8
Lazy	5.0	2.0	1.6	7.2	2.9	3.7
Lillian	5.3	1.9	1.3	1.1	0.8	2.1
Enid	6.7	1.1	9.0	1.4	0	3.6

CHEMICAL CHARACTERISTICS OF THE LAKES

The dissolved solid content (Table IV) showed seasonal variation with TDS higher in summer than autumn.

All lakes studied were alkaline with only Hiawatha ever having a *p*H in the 7–8 range.

Calcium concentrations were high in all lakes except Hiawatha. Bednorski, Lillian, and Enid were richest in calcium and were also the lakes having marl formations.

In lakes of high TDS the concentration of magnesium was greater than that of calcium. Large seasonal fluctuations in magnesium and calcium were apparent in all lakes.

Hiawatha, Bednorski, and Enid lakes had clinograde oxygen curves in summer (Fig. 5). Orthograde oxygen distributions are exemplified by Horseshoe, Lillian, Jim Smith, Lazy, and New lakes with the latter two lakes showing slight tendency toward clinograde conditions. Kiakho had a positive heterograde oxygen curve during July and August of 1960 but in September of 1960 and July of 1961 had a typical clinograde oxygen curve.

Although a similarity in oxygen comcentrations appeared in all lakes in November, marked differences were found in March during the period of ice cover. Low concentrations were particularly evident in Enid and New lakes, where a partial "winter kill" of fish has been observed by the author.

The mean ranks (Table V) of the lakes, other than Enid, lie within a somewhat narrow range (1.6–4.1).

BIOLOGICAL CHARACTERISTICS OF THE LAKES

Hiawatha, Horseshoe, and Bednorski lakes had low primary productivity (94–99 mg C/m^3 per day), whereas Kiakho, Jim Smith, New, and Lazy had moderate productivity (238–329 mg C/m^3 per day). High gross primary productivity was observed in Enid and Lillian lakes (867–964 mg C/m^3 per day). The minimum gross primary productivity was observed in Hiawatha and the maximum in Lillian. Eberley (1959) recorded a mean production rate in Myers

TABLE IV. Chemical analyses in ppm of water samples for the nine lakes for 1960 and 1961.

		Hiawatha	Kiakho	Horseshoe	New	Jim Smith	Bednorski	Lazy	Lillian	Enid
TDS[a]	Summer	53	94	111	144	168	268	300	462	1183
	Autumn	58	116	115	149	193	259	326	478	1371
*p*H[a]	Summer	8.2	8.8	8.4	8.7	8.5	8.5	8.9	8.8	9.2
	Autumn	8.1	8.2	8.4	8.5	8.5	8.6	8.6	8.7	8.9
Total alkalinity	Mean	47	73	87	123	145	189	132	249	356
	Range	28–60	50–87	70–124	86–162	104–187	135–241	98–164	147–406	280–560
Phenol.[b] alkalinity	Mean	1.0	4.5	5.5	6.0	9.0	13.0	11.0	11.5	37.0
	Range	0–2	3–6	5–6	5–7	8–10	12–14	10–12	9–14	34–40
S as SO_4	Mean	0.8	1.0	1.0	0.5	1.1	12.8	35	36	132
	Range	0–3	0–2	0–2	0–1	0–3	0–48	20–37	22–80	79–195
MgO	Mean	5.2	12.1	18.5	25.9	35.7	41.3	73.9	94.0	271.7
	Range	4–6	10–15	13–36	19–46	29–50	10–50	60–79	65–105	153–357
CaO	Mean	16.3	32.5	46.3	44.6	49.7	64.7	41.3	58.5	84.4
	Range	11–24	28–38	33–86	34–64	33–55	24–80	34–66	39–75	16–236
SiO_2	Mean	6.2	14.4	9.6	14.4	15.9	11.8	9.7	10.1	8.6
	Range	2–12	2–27	8–12	2–20	12–18	10–16	6–11	9–11	6–11
$Al_2O_3 + Fe_2O_3$	Mean	2.1	2.7	2.6	2.1	2.6	3.1	2.7	2.9	4.1
	Range	0–3	0–3	2–4	1–3	1–4	1–5	1–4	2–4	2–7

[a]Summer and autumn averages for 1960 only.
[b]Phenolthalein.

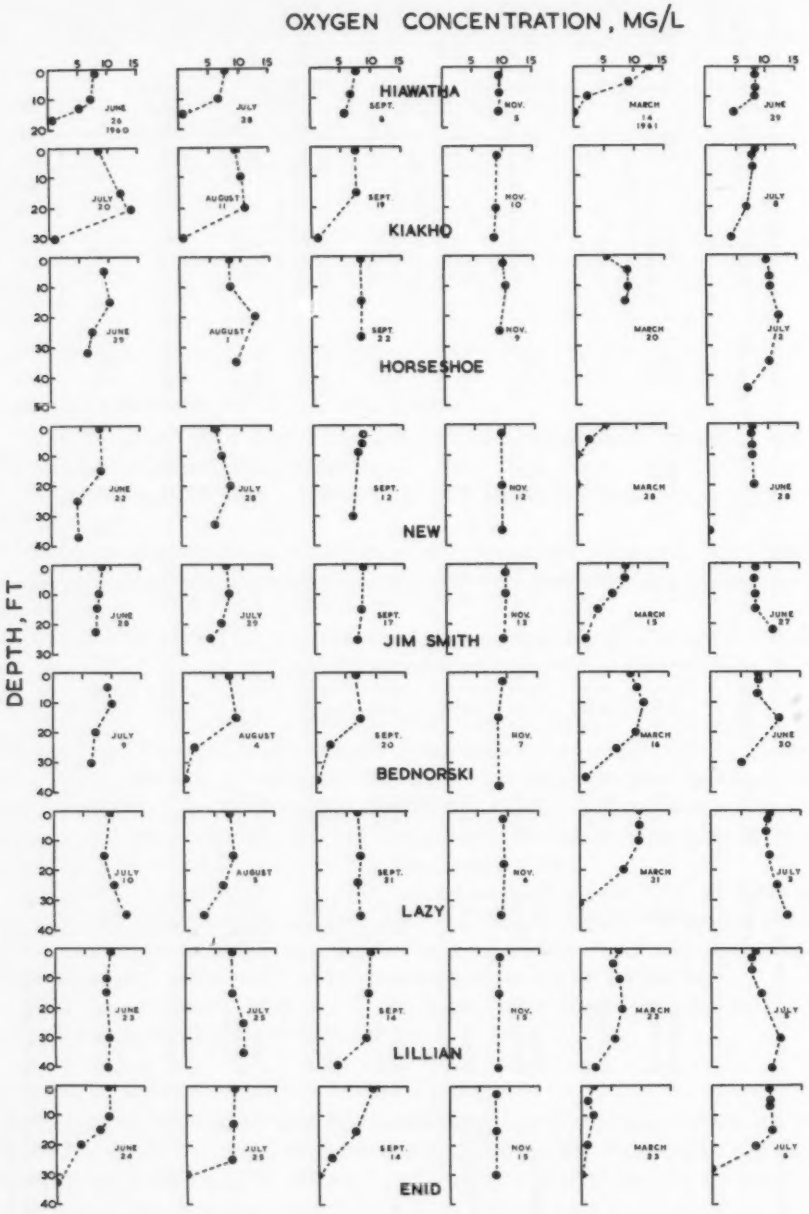

FIG. 5. Variation of dissolved oxygen (milligrams per liter) with depth (ft) in thenine lakes during 1960 and 1961.

TABLE V. Ranking of the lakes by chemical factors.

Lake	Mean TDS	Mean MgO	Mean CaO	Mean SiO_2	Mean bottom oxygen (summer)	Mean rank
Hiawatha	0	0	0	0	8.0	1.6
Kiakho	0.4	0.2	2.1	7.6	8.5	3.8
Horseshoe	0.4	0.4	4.0	3.2	5.5	2.7
New	0.7	0.7	3.8	7.6	3.6	3.3
Jim Smith	1.0	1.0	4.4	9.0	1.6	3.4
Bednorski	1.5	1.2	6.4	5.2	6.0	4.1
Lazy	2.0	2.3	3.3	3.3	0.3	2.2
Lillian	2.9	3.0	5.6	3.6	0	3.0
Enid	9.0	9.0	9.0	2.2	9.0	7.6

Lake, Indiana, of 754 μg O_2/liter (282 mg C/m^3 per day) with daily gross primary production rates as high as 1377 μg O_2/liter in the metalimnion. Weber (1958) has given a maximum rate of 300 mg C/m^3 per day for West Okoboji Lake in Iowa. Both lakes are classified as mesotrophic or intermediate between oligotrophic and eutrophic by the authors. Lakes in this study could be classed as mesotrophic or eutrophic based on gross primary production values. Total dissolved solids appeared correlated with gross primary productivity ($r = +0.74$). However, standing crops of plankton, bottom fauna, or fish were not correlated with gross primary productivity.

Enid, Lillian, Lazy, and Bednorski as lakes of highest TDS had Chara as the dominant aquatic plant. Macrophytes were found in greatest abudance in Hiawatha, New, and Jim Smith with *Potamogeton*, *Nuphar*, *and Chara* as the major genera. These lakes had low mean depths and during the summer, Hiawatha and New had approximately one-half of their surface areas covered by emergent aquatic plants. The littoral substrate of Horseshoe Lake, in large part, was composed of gravel. This factor coupled with major water level fluctuation was the probable reason for very few aquatic plants in Horseshoe Lake.

An analysis of variance of plankton volumes, obtained from six sample periods in 1960 and 1961, showed differences ($P < 0.01$) between lakes and between periods of sampling. Using a multiple range test (Duncan, 1955), Horseshoe, Bednorski, Hiawatha, and Kiakho lakes had the highest standing crops of plankton (Table VI). Of the five remaining lakes, Enid, Jim Smith, and Lazy had greater plankton volumes than New or Lillian. Zooplankton volumes were largest in early summer of 1960 and smallest during early spring of 1961. No significant statistical difference could be detected between samples obtained in late fall of 1960 and those collected from all lakes during the summer of 1961. Ranking based on average weights of plankton samples was similar to ranking based on plankton volumes except mainly for Bednorski and Enid lakes (Table VI).

TABLE VI. Average dry weights and volumes of plankton obtained in the nine lakes at all seasons during 1960 and 1961.

	Hiawatha	Bednorski	Kiakho	Horseshoe	Lazy	Jim Smith	Enid	New	Lillian
Dry weight (mg/m^3)	131.0	75.7	99.1	100.4	68.3	41.3	158.1	22.9	33.3
Dry weight (kg/ha)	16.9	28.5	18.6	27.1	25.5	8.5	47.9	7.9	11.3
Volume (cc/m^3)	17.6	16.8	12.4	12.3	11.5	8.6	6.0	4.9	4.7

TABLE VII. Corixidae and Notonectidae collected in the nine lakes in October of 1963.

	Hiawatha	Kiakho	Horseshoe	New	Jim Smith	Bednorski	Lazy	Lillian	Enid
Hesperocorixa michiganensis (Hungerford)	+			+	+	+			
Hesperocorixa vulgaris (Hungerford)	+			+	+	+		+	
Hesperocorixa atopodonta (Hungerford)	+								
Hesperocorixa leavigata (Uhler)			+						
Cenocorixa bifida (Hungerford)			+						
Cenocorixa utahensis (Hungerford)									+
Callicorixa vulnerata (Uhler)	+			+	+				
Sigara (Vermicorixa) solensis (Hungerford)									+
Sigara washingtonensis (Hungerford)		+							
Sigara (Arctosigara) penniensis (Hungerford)	+			+					
Sigara decoratella (Hungerford)				+			–		
Dasycorixa hybrida (Hungerford)									+
Notonecta undulata (Say)	+		+	+	+	+		+	+
Notonecta kirbyi			+	+					

Daphnia sp. was represented in plankton samples from all lakes and *Diaptomus* sp. from all but Lazy Lake. *Ceriodaphnia* sp. and *Cyclops* sp. were other forms of zooplankton commonly observed.

Collections of Corixidae and Notonectidae exhibited a variety of species in most lakes (Table VII).

Many of the same taxonomic groups were represented in the bottom fauna of all lakes except Enid (Fig. 6). Noteworthy were the absence of amphipods in bottom dredge samples from Hiawatha and the presence of only chironomids and amphipods in Enid. *Hyalella azteca* was observed in Hiawatha but was not present in bottom dredge samples. Additional groups classified as "others" in Fig. 6 were Trichoptera, Coleoptera, and Nematoda.

Dipterans, represented by chironomids and culicids, were the most abundant bottom organisms in all but Bednorski and Enid, where amphipods were most numerous. Diptera accounted for 93% of the organisms obtained from bottom samples in Horseshoe Lake and 30% in Bednorski Lake.

The average number of bottom organisms per dredging in the 0–20 ft region was higher ($P < 0.05$) than the average number per dredging in the region over 20 ft in Jim Smith, Bednorski, and Lazy lakes. No significant difference was indicated in other lakes.

Rainbow trout (*Salmo gairdneri*), Eastern Brook trout (*Salvelinus fontinalis*), and cutthroat trout (*Salmo clarki lewisi*) were the major species taken in gill nets from the nine lakes. Northern squawfish (*Ptychocheilus oregonensi*) were present in Bednorski Lake and redside shiners (*Richardsonius balteatus*) were found in Lazy and Bednorski lakes. Longnose suckers (*Catostomus catostomus*) were found in Hiawatha Lake.

Areal absolute hypolimnetic oxygen deficits related to the hypolimnion surface showed a range of 0.0077–0.0496 mg/cm^2 per day only and Bednorski Lake would be classified as eutrophic, according to the limits set by Hutchinson (1957) of 0.033 mg/cm^2 per day. The low oxygen deficit values were probably due to the depths of the lakes; Deevey (1940) gave similar low values for shallow lakes in Connecticut. Mean hypolimnial oxygen deficits ranged from 0.022 to 0.049 cc/liter per day, with the highest mean values in lakes of smallest volume.

Sedimentation collectors suspended for a 10-day period during September 1961, collected varying amounts of plankton in the nine lakes. Inorganic matter in suspension was not a noticeable characteristic of the study lakes. Sediment volumes varied from 0.2 cc for Enid to 3.3 cc for Lazy (Sparrow, 1963). Bednorski, Lazy, and Kiakho lakes, which exhibited the highest net plankton volumes, also had the greatest sedimentation rates. The remaining lakes had similar quantities of sediment (0.5 to 0.2 cc).

Bednorski had the highest mean rank for plankton, bottom fauna, and fish whereas New and Enid lakes ranked low for the same standing crop measurements (Table VIII). Lakes other than these three did not show consistency of rank for these three factors. For other factors indicating productivity, no

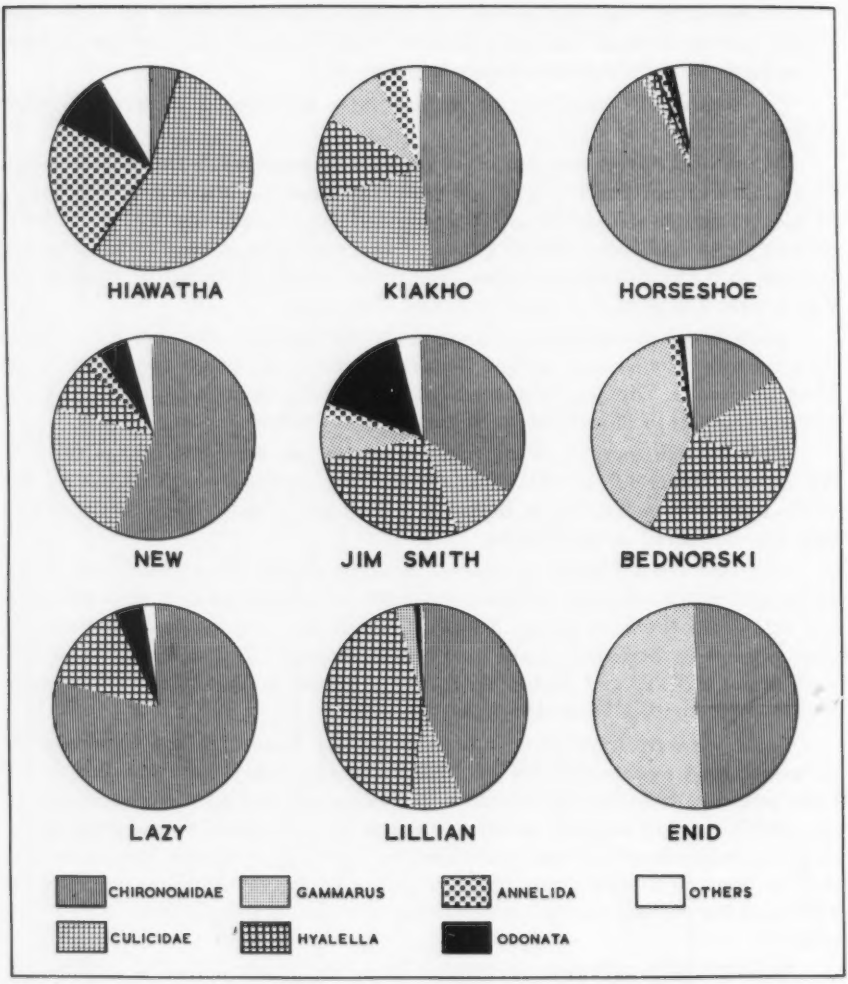

FIG. 6. Relative abundances of benthos in bottom samples taken from the nine lakes. Based on averages of all bottom organisms taken from dredge samples on six dates in 1960 and 1961.

general relationship appears evident except perhaps that Hiawatha and Horseshoe lakes were consistent in having a low rank for all three productivity measurements.

DISCUSSION

While it may be true that mean depth, climate, or some edaphic factor is singly most important in influencing productivity in a broad geographic area

TABLE VIII. Ranking of the lakes by standing crops and other biological measures of productivity.

	Plankton	Bottom fauna	Fish	Mean rank	Mean hypolimnion deficit	Gross primary productivity	Sedimentation rate	Mean rank
Hiawatha	9.0	0	1.6	3.5	0	0	0.6	0.2
Kiakho	5.3	9.0	4.6	6.3	4.1	1.5	2.9	2.8
Horseshoe	5.3	4.8	7.4	5.8	[a]	0	0.9	0.4
New	0.1	4.2	0.8	1.7	1.5	1.9	0	1.1
Jim Smith	2.7	3.2	2.4	2.8	0.1	1.6	0.3	0.7
Bednorski	8.4	6.3	9.0	7.9	9.0	0	5.0	4.7
Lazy	4.8	2.5	0	2.4	0.2	2.4	9.0	3.9
Lillian	0	5.3	2.9	2.7	0	9.0	0.3	3.1
Enid	0.9	3.8	0.1	1.6	0	8.0	0	2.7

[a]Omitted owing to extensive water-level fluctuation.

(Rawson, 1955; Northcote and Larkin, 1956), various factors by their interaction modify expression of the primary factors in lakes within a restricted geographic region.

Few studies have been undertaken using lakes which were morphometrically similar and which were situated within a restricted geographical area. Reimers et al. (1955) examined 10 lakes within a restricted region and found almost complete disagreement of physical and chemical factors with standing crops of invertebrates; trout growth was related to quantities of dissolved nutrients. On the other hand, Rawson (1960) obtained good agreement of five physical factors (TDS included) with the "score" of three biological factors. These lakes were widely scattered throughout a large area of Saskatchewan and exhibited greater morphometric differences than those in this study.

Complete agreement of physical or chemical ranking with biological ranking of the lakes in the southern Rocky Mountain Trench (Table IX) was not evident. Ranking by combining physical and chemical factors disagreed with ranking by biological or other factors indicating productivity. However, mean summer plankton volumes did appear to be related to mean hypolimnial oxygen deficits (Fig. 7).

Standing crops of plankton, bottom fauna, and fish in the nine lakes failed to correlate with a wide range of TDS. Also, mean depths and epilimnion temperatures were not correlated with standing crops of organisms. A regression of $+0.64$ ($P = < 0.10$) was obtained when lake perimeter-to-area ratios were plotted against mean plankton volumes. Therefore, length of shoreline or littoral zone per unit of area may have contributed to high standing crops of plankton.

Lazy, and in particular Horseshoe Lake, have major seasonal water level fluctuations which may have contributed to the respective low to moderate standing crops of bottom organisms. Gammarids were not represented in bottom dredge samples in either lake. Larkin and Northcote (1958) mention the possible effect on littoral bottom organisms resulting from appreciable water

TABLE IX. Ranking of the lakes by physical, chemical, and biological characteristics as well as other factors indicating productivity.

	Physical	Chemical	Physical and chemical	Biological	Other factors indicating productivity
Hiawatha	6.2	1.6	3.9	3.5	0.2
Kiakho	4.2	3.8	4.0	6.3	2.8
Horseshoe	5.0	2.7	3.8	5.8	0.4
New	2.3	3.3	2.8	1.7	1.1
Jim Smith	3.3	3.4	3.3	2.8	0.7
Bednorski	3.8	4.1	3.9	7.9	4.7
Lazy	3.7	2.2	2.9	2.4	3.9
Lillian	2.1	3.0	2.5	2.7	3.1
Enid	3.6	7.6	5.6	1.6	2.7

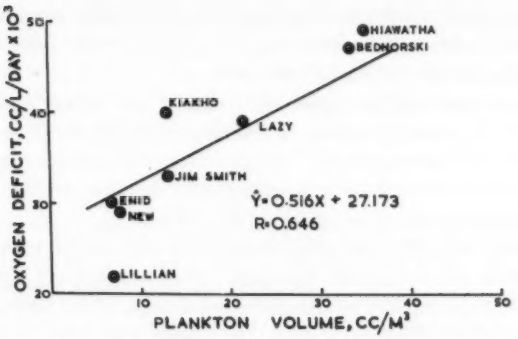

FIG. 7. Relationship of average summer plankton volumes to mean hypolimnial oxygen deficits for eight of the lakes during June–August, 1960.

level fluctuation. Grimås (1961) states that *Gammarus* sp. were heavily reduced with water level fluctuation in Lake Blåsjön, Sweden. Rooted macrophytes would likewise be influenced by water fluctuations which may have accounted for their absence from Horseshoe and Lazy lakes.

U-shaped lake basins with narrow littoral zones were characteristic of Bednorski, Jim Smith, and Lazy lakes (Fig. 2). These were the only lakes where significant differences were observed between the average numbers of bottom organisms per dredging, above and below 20 ft in depth.

New and Hiawatha lakes, with large areas less than 20 ft in depth, had abundant aquatic plants. The importance of macrophytes to the production of bottom fauna has been stressed by Rawson (1930), Ball (1948), and more recently Wohlschlag (1950). Hiawatha, New, and Jim Smith lakes with numerous aquatic plants had a greater variety of bottom fauna (Fig. 6) than did lakes with sparse aquatic flora, but did not have large standing crops of bottom fauna (Table VIII).

The lush aquatic vegetation of New and Hiawatha lakes was presumably responsible for oxygen loss during winter stagnation (Fig. 5). Patalas (1960), mentioned lack of oxygen as a factor limiting available areas for bottom fauna. Hiawatha Lake had a low standing crop of bottom fauna whereas New Lake was moderate for bottom fauna but had winter fish mortality associated with low oxygen concentrations. Although few aquatic plants were present in Enid Lake, a low standing crop of fish reflected the results of winter kill. The limited qualitative bottom fauna of Enid Lake (Fig. 6) was probably due to oxygen stagnation.

Larkin (1964) stated that a small surface-to-volume ratio may mean less heat per unit of volume from circulation. This could have been the main reason for low epilimnion temperatures in Bednorski and Lillian lakes and high temperatures in Hiawatha Lake. Rawson (1942), and Northcote and Larkin (1956) have shown a significant relationship between summer epilimnion temperatures

and standing crops of plankton. The highest mean epilimnion temperature was associated with plankton abundance in Hiawatha Lake and the lowest temperature with meagre plankton in Lillian Lake.

Perimeter-to-area ratios appeared related to mean summer plankton volumes. Length of growing season or the large volume per unit area may mask the effects of "littoral development" on standing crops of organisms. The littoral zone should exhibit the greatest productivity because of the overlap of the productive upper and lower surfaces in this area.

Ball and Hayne (1952) recorded changes in bottom fauna with removal of the fish population. In Bednorski and Lazy lakes, numbers of bottom organisms per dredging were lowest in the littoral zone. Since both lakes contain redside shiners which frequent the littoral zone, the faunal reduction may have resulted from grazing by fish.

Fish biomass was influenced by the species complex within lakes and the occurrence of natural reproduction in some lakes and not others. The three lakes having natural reproduction of fish, namely Bednorski, Kiakho, and Lillian, ranked as three out of the four highest by fish biomass in an overnight gill net set.

The size and nature of the drainage area (Table I) was important to the productivity of Bednorski, Lillian, and Enid lakes. The large drainage area of Bednorski was composed of calcareous sedimentary deposits which undoubtedly supplied the lake with water rich in nutrients. Soils surrounding Enid and Lillian lakes were low in phosphates (Kelley and Holland, 1961), which could have contributed to low to moderate plankton crops.

Without more extensive sampling it is difficult to say whether faunal deficiencies exist within the lakes studied. The absence of *Gammarus* sp. from some lakes has already been mentioned. Major groups such as Hemiptera were not taken in dredge samples. Differences in the number of fish species could account for differences in fish biomass.

Gross primary productivity (light and dark bottle) estimates appeared correlated with total dissolved solids ($r = +0.73$) but not with standing crops of plankton, bottom fauna, or fish.

Thus, although total dissolved solids may be correlated with productivity throughout British Columbia, within the limited geographic region of the southern Rocky Mountain Trench a number of factors interact to modify primary influences of productivity in a most complex manner.

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Mr I. Lansbury, University Museum, Oxford, and Dr Scudder kindly identified the Corixidae and Notonectidae. The author appreciated the assistance of J. V. Mackill, J. D. Varty, and M. Teraguchi during the collection of field data. I also thank the Consolidated Mining and Smelting Company for chemical analysis of all water samples.

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Northeastern Pacific Pleistocene Sea Otters[1]

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ABSTRACT

Previously known by only one fossil bone from Oregon, the record of the sea otter is supplemented by description of 11 bones newly found in Late Pleistocene deposits at San Pedro and on Santa Rosa Island and one tooth from an Early Pleistocene deposit at San Pedro, southern California, all considered representative of the living species *Enhydra lutris*. Faunal associations suggest that the animals lived with cool-water faunas in areas of shallow to moderate depth near islands. The long-accepted hypothesis that *E. lutris* evolved from "*Lutra reevei*" during the Pliocene in the North Atlantic and migrated to the North Pacific is rejected on chronologic and zoogeographic grounds. The sea otter may be a North Pacific endemic autochthon.

INTRODUCTION

The fossil record of littoral marine mammals is relatively poor when compared with that of more exclusively pelagic or purely terrestrial mammals. Considering that the area occupied in life by a littoral mammal is an elongate zone often only a few miles wide, that bones from a dead animal must be preserved before being abraded beyond recognition, that littoral deposits are generally the first to be eroded when uplift occurs, and then that the deposit containing these bones must be exposed to the view of a paleontologist, it is not surprising that few well-preserved remains of littoral mammals have been found.

The fossil record of sea otters is no exception to this generalization. The living sea otter, *Enhydra lutris*, once ranged along much of the northern coast of the North Pacific Ocean and adjacent parts of the Bering Sea, from Hokkaido around the rim of the Pacific to Cedros Island off Baja California, but this distribution is now much reduced as a result of human exploitation (Lensink, 1960). One reference to a femur of "*Enhydra* sp." from the Early Pleistocene of Oregon (Leffler, 1964, p. 54–55) indicates that a part of the present range has been occupied for many thousands of years, and, but for a casual mention of "sea otter (?)" from the later third of the Pleistocene of San Nicolas Island, California (Vedder and Norris, 1963, p. 37), there the record of sea otters ends. Pending the discovery of older and more definitive fossils, the present paper proposes to document more fully the Pleistocene history and ecologic context of sea otters in the eastern North Pacific Ocean and to discuss the zoogeographic aspects of the new records.

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DESCRIPTIONS OF FOSSIL SEA OTTERS

Bones recovered from Late Pleistocene deposits on Santa Rosa Island and at San Pedro, California, evidently represent the living species *E. lutris*. It seems to me unnecessary to present detailed tables of measurements since they would not adequately reflect the variation that I have seen in series of sea otter bones. Instead I have chosen to illustrate all of the bones (Figs. 1–4) by means of orthographically projected line drawings, which allow the taking of measurements and proportions directly from the figures. The variation in size and form seen in these bones is encompassed by that in series of modern bones of *E. lutris*.

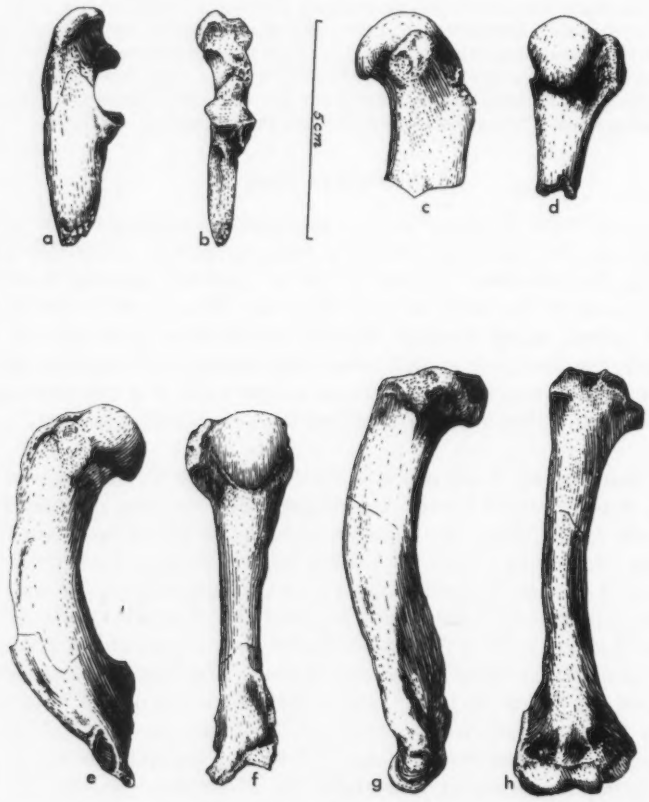

FIG. 1. Ulna and humeri of *Enhydra lutris* from Late Pleistocene of Santa Rosa Island, California. Medial (a) and anterior (b) views of left ulna (SBMNH 388); medial (c) and posterior (d) views of proximal end of left humerus (SBMNH 386); medial (e) and posterior (f) views of right humerus (SBMNH 382); medial (g) and anterior (h) views of right humerus (SBMNH 387). All views two-thirds natural size, scale is 5 cm long.

FIG. 2. Femora of *Enhydra lutris* from Late Pleistocene of Santa Rosa Island, California. Anterior (a), medial (b), and posterior (c) views of right femur (SBMNH 384); anterior (d) and posterior (e) views of proximal end of right femur (SBMNH 383); posterior (f) and anterior (g) views of proximal end of left femur (SBMNH 385). All views two-thirds natural size, scale is 5 cm long.

Comparisons made at the Los Angeles County Museum (LACM) utilized numerous appendicular bones of modern sea otters from the Point Mugu shellmound (e.g. LACM M1070, M1379, M1378) which is so notable for well-preserved bones of otters and pinnipeds (Lyon, 1937), as well as bones from the prolific middens on San Nicolas Island (Meighan and Eberhart, 1953) and San Miguel Island (e.g. LACM EDM 343, 114, 177), a complete skeleton from Cambria, California (LACM M1602), and other teeth and bones of the modern sea otter *E. lutris*. Comparisons at the UCMP made use of modern jaw number 58878a and the Pleistocene femur described by Leffler

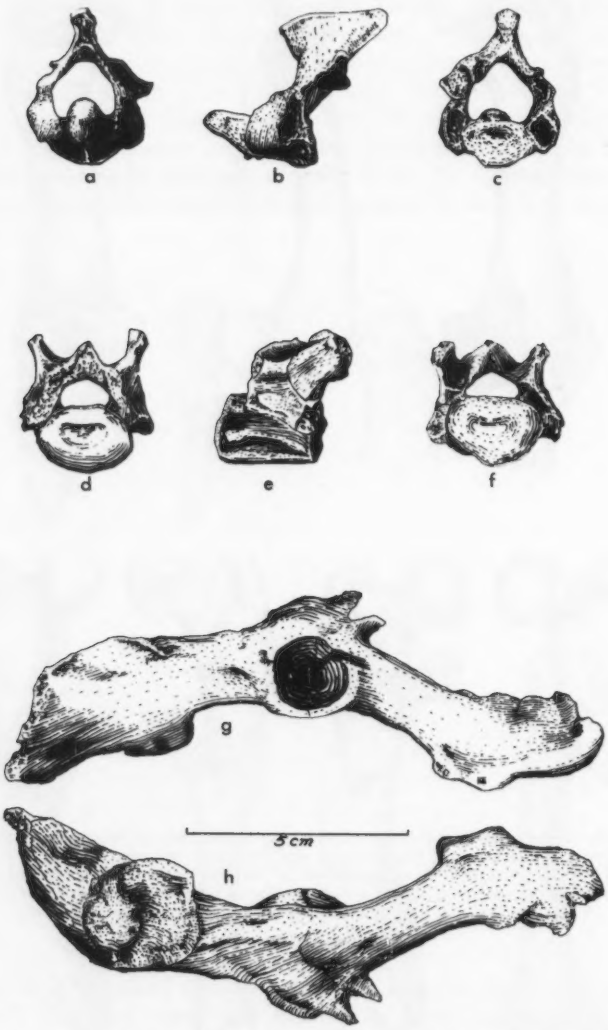

FIG. 3. Vertebrae and innominate bone of *Enhydra lutris* from Late Pleistocene of Santa Rosa Island, California. Anterior (a), left lateral (b), and posterior (c) views of axis (SBMNH 389); posterior (d), right lateral (e), and anterior (f) views of fifth (?) lumbar vertebra (SBMNH 391); right lateral (g) and medial (h) views of right innominate bone (SBMNH 390). All views two-thirds natural size, scale is 5 cm long.

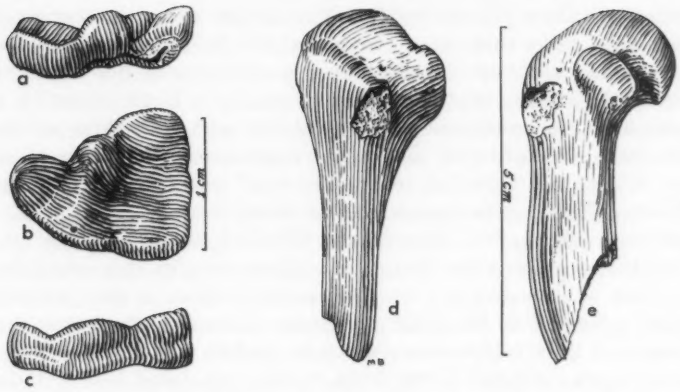

FIG. 4. Lower left deciduous carnassial tooth (LACM 4568) of *Enhydra* cf. *E. lutris* from Early Pleistocene of San Pedro, California; lingual (a), occlusal (b), and buccal (c) views, twice natural size (scale is 1 cm long). Proximal end of right humerus (UCMP 38215) of *Enhydra lutris* from Late Pleistocene of Palos Verdes, California; anterior (d) and medial (e) views, natural size (scale is 5 cm long).

(University of California Museum of Paleontology, UCMP 59889); and at the Museum of Vertebrate Zoology, University of California, Berkeley (MVZ) the following modern specimens were studied — MVZ 33583a, 123195, 123193, 6956, and 119829. A single, modern specimen, number 1694, in the collections of the Department of Zoology, University of California, Los Angeles (UCLA) was examined. Many of the fossil bones are in the Santa Barbara Museum of Natural History, Santa Barbara, California (SBMNH).

Ten postcranial bones, including SBMNH 382, a right humerus lacking the distal end; SBMNH 383, a right femur lacking the distal end; SBMNH 384, a complete right femur; SBMNH 385, a left femur lacking the distal end; SBMNH 386, the proximal end of a right humerus; SBMNH 387, a right humerus missing the proximal epiphysis; SBMNH 388, the proximal end of a left ulna; SBMNH 389, a second cervical vertebra or axis; SBMNH 390, part of a right innominate bone; and SBMNH 391, a fourth or fifth lumbar vertebra are illustrated in Figs. 1–3. These bones were collected by field parties under the direction of Phil C. Orr over the last 17 years (Orr, personal communication, September 19, 1962) from a 2-ft thick marine phase of the Garanon Member of the Santa Rosa Island Formation which is Late Pleistocene in age (Orr, 1960). All of the specimens were found about 300–500 yards inland and about 20 yards from the back edge of the Garanon wave-cut platform in Canada Tecolote at an elevation of 20 ± 2 ft, on the northwest coast of Santa Rosa Island, Santa Barbara County, California (see Orr, 1960, fig. 1). This locality is at approximately 34°00′30″N lat and 120°11′00″W long.

The humeri (SBMNH 382, '386, 387) do not differ from humeri of *E. lutris* in any critical way. The entepicondylar foramen of 387 is of a slightly

smaller diameter than that in most modern humeri seen, the scar on the anteromedial side of the shaft near the end of the deltoid crest is shallower as in a few modern specimens, and there are other slight differences. Lyon's (1937, p. 136) comment that the lesser tuberosity is larger than the greater in *Enhydra* is not clear because such is not the case if speaking of area, but perhaps is true if considering length of projection of the tuberosities from the shaft. Almost any variation seen in the fossil bones can be duplicated by one or another of the bones from a modern series.

Much the same can be said for femora SBMNH 383, 384, and 385. Number 384, a nearly complete adult femur, is slightly smaller than most of those in the modern series examined, and differs from them in that a round scar immediately proximal to the patellar surface is deeply etched into the shaft but is absent or only incipiently present in modern bones and in the femur described by Leffler (UCMP 59889; 1964, p. 54; reproduced in Fig. 5) and also differs in being smaller with a thinner shaft and neck, and in not having a deep and pronounced scar on the posterior surface of the shaft just proximal to the lateral condyle (? for gastrocnemius muscle). Numbers 383 and 385 also seem to be slightly smaller and more finely sculptured than comparable modern specimens, and 385 in particular has a shaft that is almost round in cross-section. I consider that these differences are easily resolvable if examined in the light of variations related to age and sex.

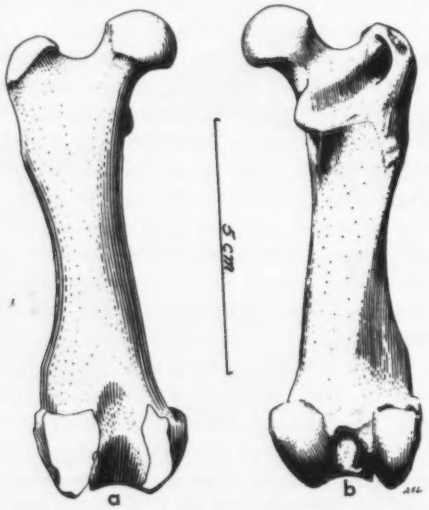

FIG. 5. Femur of "*Enhydra* sp.," best termed *Enhydra* cf. *E. lutris*, from Early Pleistocene of Cape Blanco, Oregon. Anterior (a) and posterior (b) views of right femur (UCMP 59889). Both views two-thirds natural size, scale is 5 cm long. (From Leffler, 1964.)

The proximal end of the ulna (SBMNH 388) is from a large individual. It is more robust than most of the 18 modern ulnae with which it was compared, but otherwise differs from them only slightly. For example, the posterior border of the shaft just proximal to the missing portion is slightly straighter, an observation which might indicate that the once-complete bone was just a little less bowed than the modern specimens. This is a very small difference however.

I can find no dependable differences between the fossil axis (SBMNH 389) and modern axes like LACM M1602 and UCLA 1694, and this again emphasizes the probable conspecific nature of the species represented by the fossil material and the modern sea otter.

Comparison of the innominate bone, SBMNH 390, with a series of 16 innominates in the LACM indicates that here again there is a wide range of variability in modern sea otters, and that the fossil bone can be matched with some in the series that are more finely sculptured than most.

The lumbar vertebra (SBMNH 391) lacks the neural spine, transverse processes, postzygapophyses, and other lesser structures. It conforms most closely to the fifth lumbar vertebra of skeleton LACM M1602 in the shape of the centrum and the size and arrangement of processes, but it differs from the fifth and resembles the fourth or third lumbar vertebra in having a longitudinal strut on the midventral floor of the neural canal. This strut is bordered by deep sulci which contain a pair (one on each side) of large nutrient foramina in the modern LACM specimen and in MVZ 119829 as well, but these foramina are absent in the fossil, as are the one or two large foramina on the ventral face of the centrum found in the second to fourth lumbars of the modern specimen. However, MVZ 119829 shows these conditions (seen in the fossil) in the fifth lumbar, and this specimen also agrees with the fossil in having wide prezygapophyseal articulation.

These bones, then, from the Late Pleistocene of Santa Rosa Island almost certainly indicate that *E. lutris*, the living species of sea otter, has been an inhabitant of the California Channel Islands region for thousands of years. Another occurrence of a bone from the Late Pleistocene of the mainland of California serves to bear out the above conclusion.

This second occurrence consists of a proximal end of a right humerus, UCMP 38215, which was collected by Loye H. Miller in 1912 from UCMP locality V-2047 at San Pedro, California. The UCMP catalogue cites for locality V-2047 the "Upper San Pedro Beds; immediately adjacent to the yards of the San Pedro Lumber Co. Material collected by Dr F. C. Clark of Los Angeles and J. J. Rivers — 1912." This is probably Arnold's "Lumber Yard" locality, station 113 of Woodring et al. (1946, p. 124, pl. 14; USGS locality 12135), at 33°44′54" N lat and 118°16′45" W long. These "Upper San Pedro beds" of Arnold were termed the "Palos Verdes formation" in 1926 but this name was replaced by "Palos Verdes sand" in the report of Woodring et al. (1946, p. 56). The type locality of Arnold's "Upper San Pedro series" and therefore of the Palos Verdes sand is the lumber yard locality,

cited above, whence came the sea otter bone. The Palos Verdes sand is Late Pleistocene in age, the youngest of the terrace deposits in the area (Woodring et al., 1946).

Humerus UCMP 38215 is slightly abraded, but in comparison with a series of about 15 humeri (LACM EDM 343, 177, 114, etc.) slight differences can be found. The head (Fig. 4) does not project back over the shaft quite so far as in the modern specimens examined, the crest of the lesser tuberosity is thinner and forms more of a flange than in most of the modern specimens, and the shaft is perhaps slightly straighter, but little else is noteworthy. At the risk of being repetitive I wish to emphasize that here again the almost exact morphological agreement of the modern and fossil bones suggests conspecificity.

But, except for the femur described by Leffler, these foregoing records are all of Late Pleistocene age. Are there not older fossils that will help elucidate the evolutionary history of sea otters? Only two fossils are known to me older than Late Pleistocene; the femur described by Leffler (1964) and a single tooth from the Timm's Point Silt at San Pedro, California. More specifically, the tooth is a complete crown of a lower left deciduous carnassial, number LACM 4568, collected at San Pedro, California, by Patrick LaFollette in 1961. LaFollette told me that he collected the specimen at LACM Invertebrate Paleontology locality 130-7, for which the entry in the LACM catalogue reads: "130. An exposure made by the Museum party in seven points across the railroad tracks at Fisherman's Slip, Berth 79, San Pedro, California, about 300–400 yards south of Loc. 129. Material of a better state of preservation was collected at one to four feet above the level of railroad tracks. Lower Pleistocene, Timm's Point formation. (See G. P. Kanakoff notes: 7-8-1947)." The "−7" appended to the locality number evidently refers to one of the seven pits, perhaps the last or most recent one. This locality is probably equivalent to locality 32c (USGS locality 12213) of Woodring et al. (1946, p. 45 and 122, pl. 14), which falls in their "Unit 1" of the Timm's Point Silt. It is located at 33°43′55" N lat and 118°16′42" W long. Woodring, et al. (1946) noted that both foraminifera and mollusks as well as other megafossils occur in the unit from which the sea otter was collected, and that the locality has been a well-known collecting station for many years. The Early Pleistocene age of the Timm's Point Silt seems to be well established (Durham, 1954, fig. 2).

At first sight this tooth, LACM 4568, looks utterly unlike the bulbous and inflated cheek teeth so characteristic of sea otters, but it does compare favorably with an illustration (Jacobi, 1938, abb. 16) and specimens (MVZ 33583a, 123195, 123193, 6956, and UCMP 58878a) of left lower deciduous fourth premolars of *E. lutris*. A small pit on the tip of the hypoconid of the fossil is duplicated on the apex of the protoconid on both left and right deciduous fourth premolars of MVZ 6956 and 33583a. These pits might be the result of dental caries or more probably abrasion pits due to wear through the enamel into the dentine.

The fossil tooth, LACM 4568, compares most favorably with MVZ 33583a and differs from the other teeth in having a deeper sulcus between the paraconid and metaconid that runs ventrally almost to the base of the crown enamel, and also in having a more deeply formed fossa which comprises the talonid basin between the hypoconid, entoconid, and metaconid. The posterior border of this talonid basin is a straight, rounded torus in UCMP 58878a and MVZ 33583a; is straight with a sharp posterodorsal border in MVZ 123195, 6956, and 123193; but is not so straight and is semirounded in the fossil tooth. That is to say the torus is interrupted by a slight sulcus in the vicinity of the deep portion of the talonid basin, and the torus is therefore sinuous in posterior view. The fossil is more like UCMP 58878a and MVZ 123193 in having generally more sharply differentiated crests and sulci, but is slightly larger than most of the specimens except MVZ 33583a in total size. An incipient cingulum found on the external or labial side of the fossil tooth is also found in some, but not all, of the modern teeth. The valley between the protoconid and hypoconid has a flatter bottom in the fossil, and other slight differences might be enumerated but these are easily accounted for by individual variation. In my opinion the fossil tooth matches those of *E. lutris* well enough to be referable to the living species.

The tooth from the Early Pleistocene of San Pedro, the Timm's Point Silt specimen, suggests that a sea otter referable to the living species inhabited an area that is now near the southern end of the range of *E. lutris* in the eastern North Pacific, which is Morro Hermoso, Baja California (Ogden, 1941, p. 7–8). Little more than this can be said about the Pleistocene history of sea otters, since the documented fossil record of *Enhydra* consists of only 12 bones and one tooth which have been collected from four localities.

ECOLOGY AND FAUNAL ASSOCIATIONS

Did these Pleistocene sea otters have the same ecological requirements as the modern populations? It is perhaps not possible to make interpretations of so little data to any practical degree of refinement, but a brief survey of some pertinent studies may help.

Orr (1960, p. 1115) noted that in addition to the sea otter bones from the marine facies of the Garanon Member of the Santa Rosa Island Formation, remains of whales, sea lions, shore birds, and rarely, dwarf mammoth have been found. This assemblage may be termed the *Garanon Canyon local fauna*. Marine invertebrates associated with these vertebrates are representative of a cool-water fauna (Orr, 1960, p. 1115 and table 1). They suggested to Valentine and Lipps (1963, p. 1300) a rocky-shore assemblage with a northern and presumably cool-water element and with no southern species of mollusks.

More data are available relating to the deposit and fauna of the Palos Verdes Sand at the Lumber Yard locality. During the Late Pleistocene (Palos Verdes time) the Palos Verdes Hills formed an island separated from the mainland of California by shallow water (Woodring et al., 1946; Valentine,

1961, fig. 6) and the Lumber Yard locality lay on the southeast or leeward side of this island. Vertebrates from the locality of the *Lumber Yard local fauna* or equivalent deposits of the Palos Verdes Sand include ?dire wolf, felid, rabbit, squirrel, vole, gopher, ground sloths, horse, deer, antilocaprid, camel, and bison (Stock, 1925, p. 118) and the deposit suggested strand-line conditions to Stock. Woodring et al. (1946, p. 86) mentioned a mammoth tooth collected by W. P. Blake from the Palos Verdes Sand. They also cite a sea lion (*Zalophus* sp., Kellogg, 1927) and a seal (*Phoca* sp., Kellogg, 1922) but this latter record is only cited by Kellogg (1922, p. 120) and not described by him. Miller (1912, p. 115) did not describe the seal remains but only mentioned that "seals" occurred with grebe, small turtles, sting rays, and other vertebrates in the "Upper San Pedro Pleistocene." Miller (1914) described 16 birds and mentioned the presence of "serpents" and other animals which suggested "fluviatile contributions due possibly to seasonal conditions of high water." The birds were either migratory or species of wide distribution. Miller (1930) reviewed the avifauna and enumerated additional records, and Miller and DeMay (1942, p. 57–58) listed a total of 21 birds, "?*Smilodon*" and *Elephas*, and stated that the small turtle was like the California mud turtle. Miller and DeMay agreed with Arnold's conclusion that the deposit represented sand dunes with some contributions from river floodwaters and brackish lagoons. Woodring et al. (1946, p. 86) suggested that the large terrestrial animals probably did not live on the Palos Verdes Hills island and that probably their carcasses floated out from the mainland. The sea otter also might have floated to the site of deposition. Miller (1930) and Woodring et al. (1946) have discussed the mixed faunal association at the Lumber Yard locality in the Palos Verdes Sand. Apart from the continental and marine mammals, freshwater mollusks and the mud turtle represent a freshwater aspect, and fish and marine mollusks in abundance demonstrate the marine character of the deposit. The inference of these investigators is that the area was one of shallow, current-swept, marine waters. Shallow-water bays may have extended into the island formed by the Palos Verdes Hills, especially from the strait separating the island from the mainland. The large invertebrate assemblage from the Lumber Yard locality is inferred by Valentine (1961, p. 374–375) to represent a quiet shallow-water fauna; more specifically, the Palos Verdes Sand represents chiefly a sandy beach and shallow inner sublittoral habitat running from low tide to about 15 fath with some elements of rocky shore aspect (Valentine and Meade, 1961, p. 7). The minimum sea surface temperature ranges necessary to support an assemblage from the Palos Verdes Sand at a different locality, "Crawfish Georges," are 21 C low maximum to 11 C high minimum, with a high minimum of 8 C at 15(?) fath depth (Valentine and Meade, 1961, table 12). Valentine and Meade (1961, p. 39) further state that Late Pleistocene rocky-shore associations like that from "Crawfish Georges" are known from as far south as Punta Baja, Baja California, Mexico, and that there seem to have been more extremes in water temperatures in the Late Pleistocene than today for comparable situations.

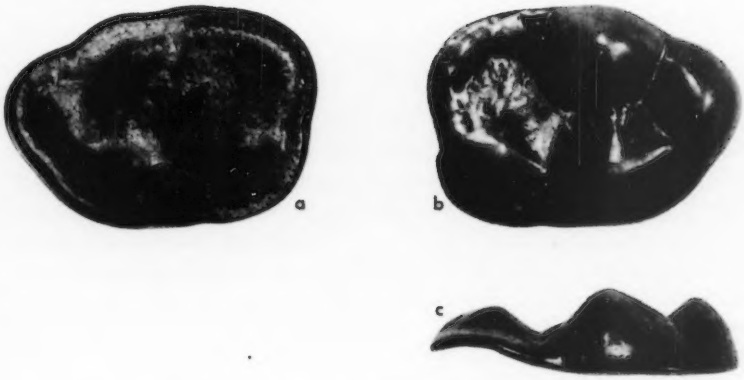

FIG. 6. Lower tooth (CM 548) of "*Lutra reevei*" from Middle Pleistocene of Bramerton, England; ventral (a), occlusal (b), and side (c) views. Newton stated that this right lower carnassial was 20 mm long (but see Pohle, 1920, p. 167). Photographs courtesy of Mr B. McWilliams.

The Timm's Point Silt, whence came the juvenile sea otter tooth, has been inferred to represent a moderate-depth range of about 50–100 fath (Woodring et al., 1946, p. 92). Shallow-water species of invertebrates are scarce in the deposit, and the *Timm's Point local fauna* has a northern aspect such that it has even been termed boreal. The Timm's Point Silt was deposited at depths between 25 and 100 fath (Valentine, 1961, p. 410) and contains an invertebrate fauna of cold-water species of distinctly northern aspect. Inferred minimum sea surface temperature ranges necessary to support this fauna are 14 C low maximum and 11 C high minimum, with a high minimum of 6 C at 50 fath (Valentine and Meade, 1961, table 12).

These data suggest, then, that the known fossil sea otters from southern California have been found associated with cool-water faunas in rocks deposited in shallow to moderate depth near islands.

SEA OTTER ORIGINS

The fact has been established that sea otters of a modern type were present in the northeastern Pacific Ocean in the Early and Late Pleistocene, probably occupying environments comparable with those preferred by living populations in the same area today. How does this fact compare with speculations on the origin of sea otters?

The theoretical derivation of *Enhydra* from known Pliocene lutrines has been disputed. For example, Winge (1941, vol. 2, p. 239) stated that *Enhydra* was derived from *Lutra*, while Gregory (1951, pl. 20.1) placed *Enhydriodon* (Pliocene of Europe, Asia, and Africa: Simpson, 1945) in an ancestral position following among others Pohle (1920) and Zdansky (cited by Matthew, 1929). But Matthew (1929, p. 472) has pointed out that "it does not appear that the specialization of *Enhydriodon* is in the direction of *Enhydra*" and this has been echoed by Barabash-Nikiforov (1962). According to Thenius and Hofer (1960, p. 166) the best ancestor for *Enhydra* as presently understood is "*Lutra reevei*"[3] from the "englischen Pliozän." *Potamotherium* (Oligocene and Miocene of Europe: Simpson, 1945) has been supposed by many to be "the ancestral type for otters" (Matthew, 1929), but may in fact be too specialized to be considered as an ancestor of *Lutra* (Savage, 1957, p. 161; Piveteau, 1961, p. 748).

Without considering the possible ancestry of the genus *Lutra*, problems enough are encountered if, as has been suggested, "*Lutra reevei*" from the Atlantic Ocean is ancestral to *Enhydra*. Newton (1890, p. 446) named the species on the basis of a "germ-tooth" that he called a "right lower carnassial"

[3]Kretzoi (1961, p. 516n) believed that "*Lutra reevei*" was a sea otter, representing a stage between *Enhydra* and true lutrines, and accordingly placed a suggestive generic name on the species of Newton, "*Plesiolatax reevei*." I have been unable to see or otherwise verify this reference (Miklós Kretzoi, 1961, Felsö — Pannóniai Fauna Galgamácsáról. Magyar Áll. Földtani Intézet Évi Jelentése Az 1957–1958. Évröl., p. 513–524).

found by James Reeve, the curator of the Norwich Museum, in "the lower beds of the Norwich Crag at Bramerton," East Anglia, England. Thus there is the problem of migration between oceanic basins, but this can be resolved. Since there was one and probably more Central American seaways open in the Pliocene (Simpson, 1950, p. 363; Whitmore and Stewart, 1965), since there was no land bridge directly between North America and western Europe in the later Tertiary (Simpson, 1947, p. 658–659), and since there was intermittent free access in the Late Pliocene and Pleistocene between the Arctic and North Pacific (Hopkins, 1959; Hopkins et al., 1965), then North Atlantic–North Pacific interchange was possible by way of the two shortest routes at the critical time. But more importantly, the single tooth of "*Lutra reevei*" is from the Norwich Crag, thought by some to be Pliocene in age (e.g. Thenius and Hofer, 1960, p. 166) but better regarded as Early Pleistocene (Charlesworth, 1957, p. 599) or even younger (Early Middle Pleistocene: Kurtén, 1960, p. 30 and fig. 2), and is therefore younger than either the tooth from the Timms Point Silt in California or the femur from the Elk River Formation in Oregon described by Leffler (1964). Because these older North Pacific fossils are considered to be conspecific with the living sea otter, it is obvious that the "*Lutra reevei*" tooth cannot represent a direct ancestor of *E. lutris*. Indeed, Newton favorably compared the tooth of "*Lutra reevei*" with that of the "Indian Clawless Otter (*Lutra* [= *Aonyx*] *cinerea*)" in his original description (and see Thenius, 1949a, p. 319, note 4).

Detailed, systematic comparisons are beyond the scope of this study, but Mr Brian McWilliams has kindly supplied photographs of the tooth (No. 548, Castle Museum, Norwich). The lower carnassial is from a young animal (Fig. 6) and is decidedly unlike the triangular, lower deciduous carnassial from *E. lutris* (Fig. 4). Probably a newly developing permanent tooth, it nonetheless differs from teeth of adult sea otters in many ways.

The sea otter may probably be considered as a strict North Pacific endemic autochthon, just as McLaren (1960) had assumed it to be. Known marine Tertiary otter-like forms from the North Pacific or Arctic basins and adjacent continents, such as *Semantor macrurus* (Orlov, 1931a, b, 1933; Kirpichnikov, 1955; Thenius, 1949b), Macdonald's (1956) humeri of "?Mustelidae, gen. indet.," *Neotherium mirum* (Kellogg, 1931; Downs, 1956; Mitchell, 1961), and Wilson's (1935) "phocid," to mention but a few problematical forms, are all far too removed and specialized to have played a part in sea otter origins. This brief survey suggests that the ancestry of the sea otter, *E. lutris*, is to be sought in pre-Pleistocene mustelids in the North Pacific or Arctic basins.

Since it is probably not true that "the dissemination of this group may be traced along the shores of France, England, and Iceland to Greenland, where it was replaced by *Enhydra reevei*, the direct ancestor of the modern sea otter" (Barabash-Nikiforov, 1962, p. 27), a detailed re-examination of the fossil tooth called "*Lutra reevei*" should be undertaken to more clearly determine its bearing on sea otter evolution. If directly related to sea otters,

could "*Lutra reevei*" be a derived rather than ancestral form? Did the *Enhydra* stock ever spill over into the North Atlantic Ocean?

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The Acute Inflammatory Reaction in Two Different Tissues of the Pacific Oyster, *Crassostrea gigas*[1,2,3,4]

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ABSTRACT

This study describes the histopathology and the associated gross pathological alterations of experimentally induced acute inflammation in the oyster, *Crassostrea gigas*, after turpentine injections into two different tissues, the adductor muscle and the Leydig cell area. Under optimum conditions the oyster can successfully combat a toxic substance such as turpentine, with the adductor muscle being more capable of handling such an irritant than the Leydig cell area. Inflammation in vertebrates is compared with that in the oyster.

INTRODUCTION

Inflammation as an immediate and basic protective mechanism of the vertebrate body against foreign bodies and disease is well documented (Florey, 1958; Houck, 1963; Spector, 1960, 1964; Spector and Willoughby, 1963; Weinreb, 1958, 1959; and others). However, the use of invertebrates for the experimental study of the inflammatory processes has been only superficially exploited since the early work by Metchnikoff (1891).

Pathogenic agents often alter the cellular organization of the host's body and these alterations can be recognized in histological preparations. However, there have been few systematic investigations of the histological changes associated with pathogens of oysters, with a few notable exceptions such as the work of Mackin (1951, 1962) and other investigators (Mackin et al., 1952; Stein et al., 1961; Sparks, 1962, 1963; Cheng and Burton, 1965; Cheng, 1966). If one is to separate the effects of a specific pathogen from a general reaction to any pathogenic agent, it is essential that the inflammatory processes are understood. Several investigators have described non-specific inflammatory

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[4]The work reported here was part of a thesis submitted by the senior author to the Graduate School, University of Washington, in partial fulfillment of the requirements for the Master of Science degree.

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changes in association with diseases in oysters (Mackin, 1951, 1962; Mackin et al., 1952; Stein et al., 1961) and unknown causes of mortality (Fujita et al., 1953, 1955). The cellular responses and defense mechanisms of molluscs have been reviewed recently (Stauber, 1961; Cheng and Sanders, 1962; Tripp, 1963), but most of the experimental work on the defense mechanisms of bivalve molluscs (Bang, 1961; Mikhailova and Prazdnikov, 1961, 1962; Stauber, 1950; Tripp, 1958, 1960) has dealt with the phagocytic ability of these animal's leucocytes and the processes by which phagocytized materials are eliminated or destroyed. Drew and de Morgan (1910) gave a very fine account of the inflammatory process in the bivalve, *Pecten maximus*, and some preliminary observations on the inflammatory response in the oyster, *Crassostrea gigas*, were presented by Pauley and Sparks (1965).

The work reported here is a histological description of the comparative process of acute inflammation in two different tissues of the oyster's body, the Leydig cells or connective tissue and the adductor muscle, after injections of turpentine.

MATERIALS AND METHODS

Four groups of 100 oysters each were maintained in trays at the United States Public Health Service Shellfish Sanitation Laboratory at Purdy, Washington. Seawater utilized during this experiment was free flowing, maintained at a temperature between 46 F and 53 F and irradiated by ultraviolet light upon entering the laboratory. Kelly (1961) described in detail the salt water facilities of the Purdy Laboratory.

The four groups of oysters used in this experiment were as follows.

Experimental Oysters

(1) One group of oysters was injected with 0.05 ml of turpentine in the Leydig cell area above the palps after removal of a portion of the shell approximately ½ inch in diameter by a dentist drill.

(2) A second group of oysters received 0.05 ml of turpentine in the adductor muscle after removal of most of the shell posterior to the adductor muscle.

Control Oysters

(3) A group of 200 oysters had portions of their shells removed similarly to the experimental oysters and 100 of these were injected with 0.05 ml of seawater above the palp region.

(4) The other 100 oysters were injected with 0.05 ml of seawater in the adductor muscle.

The syringes and 25-gauge needles used in this experiment were heat sterilized and all seawater used for injection into oysters was filtered through an HA millipore filter to insure bacteria-free water.

Turpentine was used in this study because it is an irritative substance which initiates a typical inflammatory reaction, is used frequently in studies of inflammation in vertebrates (Weinreb, 1958, 1959) and was used previously to study inflammation in oysters (Pauley and Sparks, 1965).

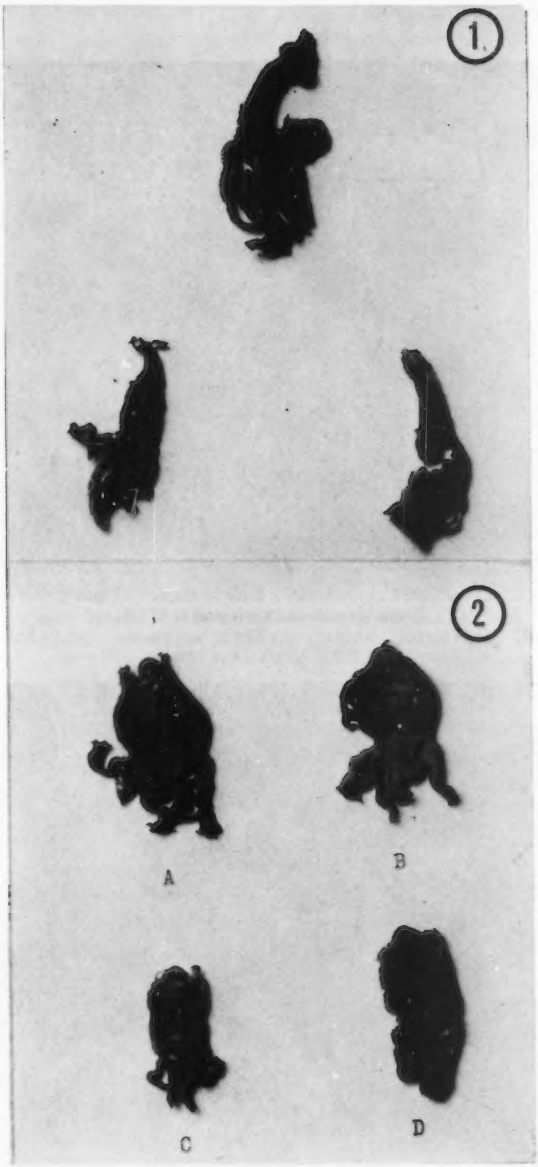

FIG. 1. Cross section of three control oysters' adductor muscles 120 to 128 hr after injection with seawater. These muscles are normal in appearance, approximately normal size.

FIG. 2. Cross section of four experimental oysters' adductor muscles 128 hr after injection with turpentine. Note the swollen appearance of the muscles when injected either directly into the muscle (A and B) or in the connective tissue area (C and D), approximately normal size.

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FIG. 3. Normal adductor muscle. Note muscle fibers (A) and blood spaces (B). Hematoxylin and eosin stain. 120×.

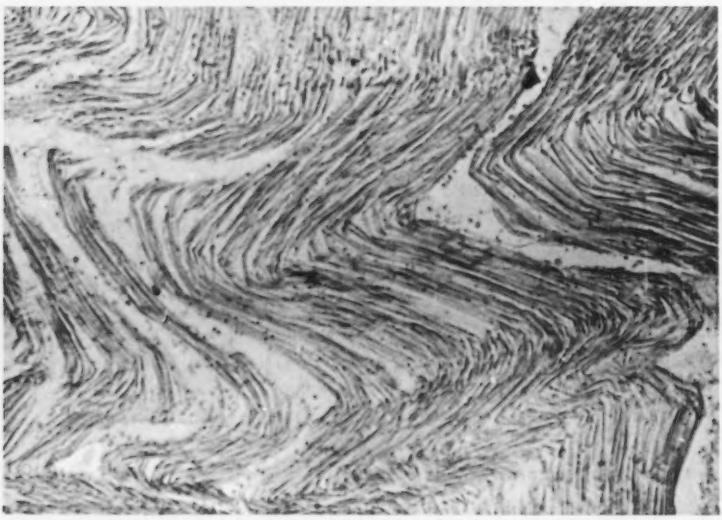

FIG. 4. Adductor muscle 40 hr after injection of turpentine. Note edema among muscle fibers, the light leucocytic infiltration, and the contorted muscle fibers. Hematoxylin and eosin stain. 120×.

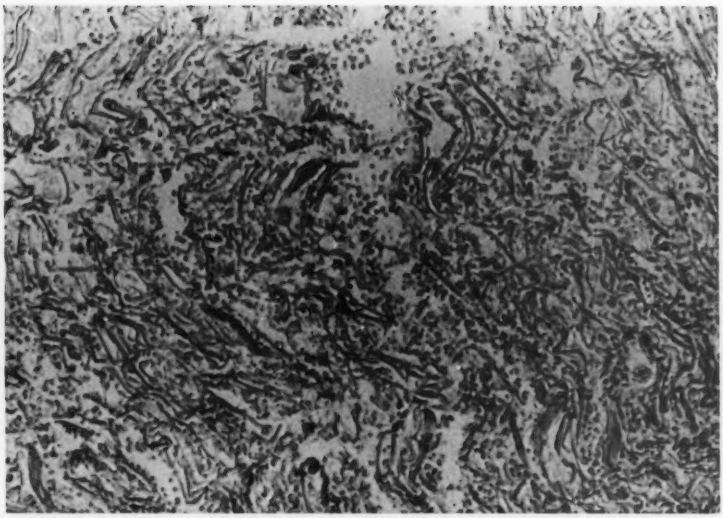

FIG. 5. Adductor muscle 100 hr after injection of turpentine. Note the heavy leucocytic infiltration and edema in the disorganized muscle fibers. Hematoxylin and eosin stain. 120×.

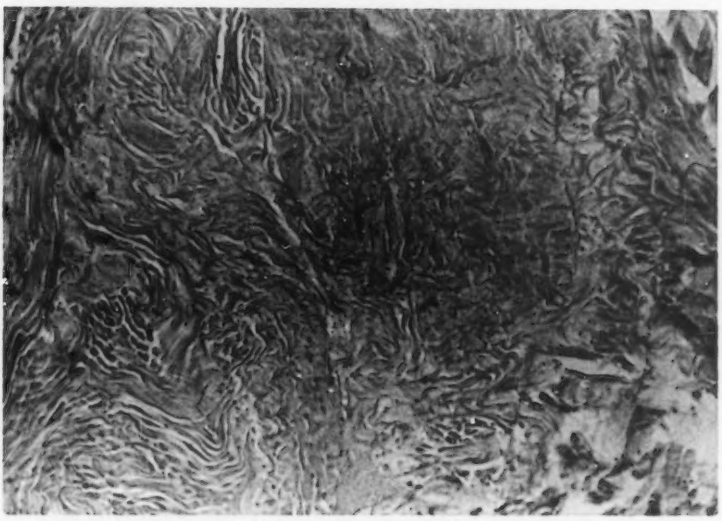

FIG. 6. Hypertrophied adductor muscle fibers 48 hr after turpentine injection. Note the disorganized appearance of the fibers. Hematoxylin and eosin stain. 120×.

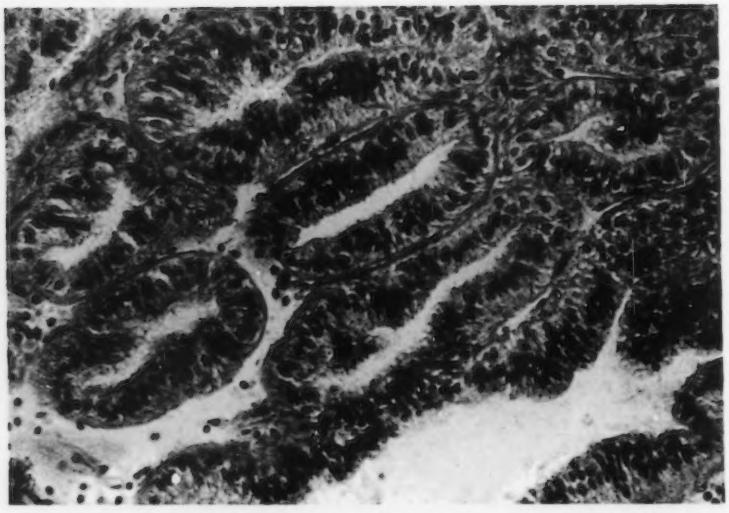

FIG. 7. Normal kidney epithelium. Hematoxylin and eosin stain. 300×.

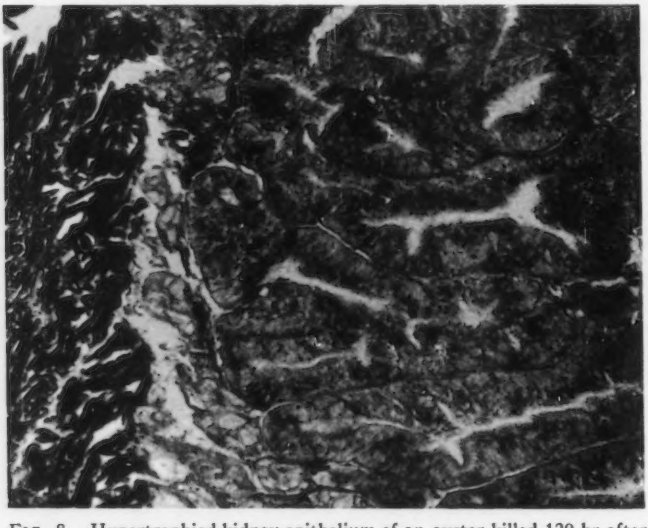

FIG. 8. Hypertrophied kidney epithelium of an oyster killed 120 hr after turpentine injection. Cells which apparently lack nuclei possess karyolytic nuclei. Hematoxylin and Mallory's trichrome stain. 120×.

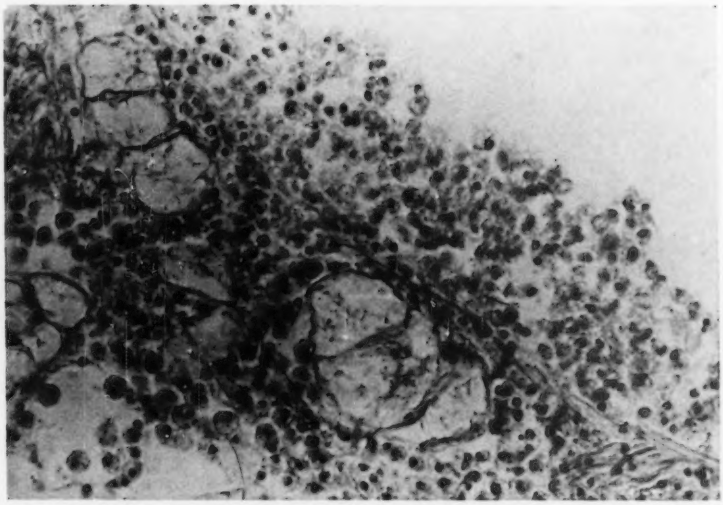

FIG. 9. Pavementing and cellular exudation from large vessel 24 hr after turpentine injection. Hematoxylin and eosin stain. 480×.

FIG. 10. Vacuolated, brown pigment cells (A); for comparison note the leucocyte (B) and Leydig cell (C). Hematoxylin and eosin stain. 425×.

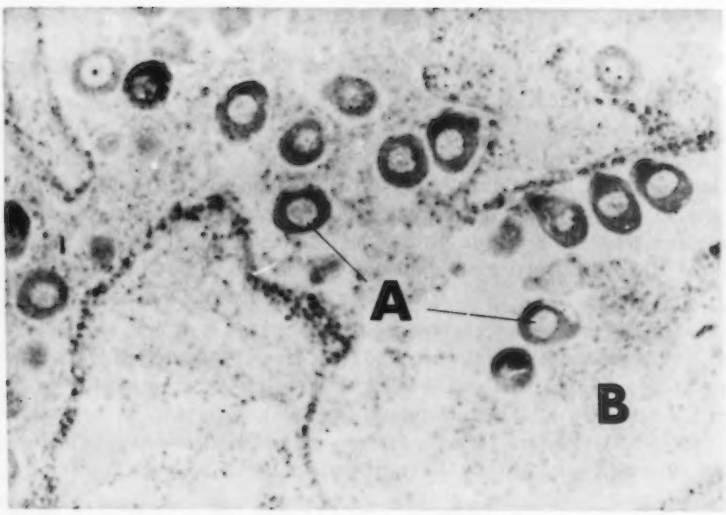

FIG. 11. Gonadal duct of resorbing female control oyster. Note eggs (A) and heavy concentration of leucocytes (B) within the gonadal ducts. Hematoxylin and eosin stain. 120×.

At 8-hr intervals until 400 hr had elapsed, two oysters from each of the four groups were carefully removed from the shell and the entire oyster was fixed in Zenker's Fixative for 8 hr. The fixed oysters were washed for 24 hr and a cross-section, approximately $\frac{1}{4}$ inch thick, containing the lesion, was taken from the site of injection. Sections approximately 7 μ thick were cut from the tissue after embedding in Paraplast and were stained with either Harris's hematoxylin and eosin or Mallory's trichrome. Experimental and control animals sampled at each time interval were stained together insuring identical treatment for the entire lot.

RESULTS

Experimental Oysters Injected in the Connective Tissue

Oysters injected in the connective tissue were normal in appearance upon gross examination until 32 hr, at which time the adductor muscle became swollen (Fig. 2, compare to Fig. 1) and incapable of holding the shell valves closed. This condition persisted until 366 hr, after which time all remaining oysters were normal in appearance, although a few oysters killed between 216 and 366 hr also appeared normal. The mantle and gills of most oysters fixed between 56 hr and 366 hr exhibited abnormal concentrations of silt, indicating that the oysters were not functioning properly.

The histological findings in this experimental group agree with those found previously by Pauley and Sparks (1965), through 212 hr, with two notable exceptions. These were: (1) ciliates, which will be discussed in a separate paper, were observed on the gills of several oysters killed after 128 hr; (2) swollen adductor muscles were noted in all oysters after 32 hr. Only one oyster, killed at 168 hr, was observed by Pauley and Sparks (1965) to have a swollen adductor muscle.

Thirty-two hr after injection, the time at which swelling of the adductor muscle was observed grossly, this organ was observed histologically to be highly edematous. After 40 hr, there was a congestion of the blood channels, a light leucocytic infiltration in most muscle tissue, and the muscle fibers were necrotic with pycnotic nuclei (Fig. 4). Many of the fibers possessed a heavy leucocytic infiltration (Fig.5) or were hypertrophied after 48 hr (Fig. 6). These conditions persisted until 104 hr, when all oysters possessed areas of coagulation necrosis in their adductor muscles.

After 120 hr, vessels in the gills and the Leydig cell area below the adductor muscle were congested and aggregations of necrotic leucocytes, which we term pus, were present in the adductor muscle and were encircled by viable appearing blood cells. The muscle fibers lacked nuclei and an extensive, spreading cellulitis was noted in the adductor muscles of several animals after 160 hr and was typical after 224 hr. After 200 hr the cells of the visceral ganglia had become necrotic, losing their staining affinity and possessing nuclei that had undergone karyorrhexis.

The epithelial cells of the kidney became hypertrophied and possessed karyolytic nuclei after 80 hr (Fig. 8, compare to Fig. 7). This necrotic epithelium began to slough away from the basement membrane at approximately 240 hr and was completely liquified in some oysters after 264 hr.

The rectum characteristically became necrotic after 224 hr and the blood spaces surrounding it were congested. The epithelium of the rectum often became ulcerated after 280 hr. The style sac and gut underwent similar changes, but somewhat earlier than the rectum, with ulcerations occurring as early as 224 hr.

With the exception of one oyster killed at 358 hr, all oysters killed after 212 hr possessed abscesses in the digestive tubule area which appeared similar to those observed by Pauley and Sparks (1965). The exception had a well-confined abscess with what appeared to be elongated leucocytes containing round nuclei at the periphery. This phenomenon was not observed in previous experiments (Pauley and Sparks, 1965), indicating that oysters maintained over a long period of time may possess the ability to repair tissue damaged by turpentine or other caustic substances, since elongate cells are usually suggestive of an advanced stage of wound repair.

Experimental Oysters Injected in the Adductor Muscle

Sixteen hr after injection of turpentine into the adductor muscles of oysters, this organ became swollen (Fig. 2) and in many cases lost its ability to close the shell valves. After 32 hr, the muscle's attachment to the shell was weakened and abnormal accumulations of silt were observed on the gills and mantle. By 48 hr, pus appeared in the area of injection. The pathologic phenomena observed at 32 and 48 hr were constant features in virtually all oysters of this experimental group for the remainder of the experiment.

Microscopic examination of oysters fixed 8 hr after injection demonstrated a localized congestion around necrotic muscle fibers. Edema was present among the muscle fibers at 24 hr. After 64 hr, the muscle fibers were hypertrophied with faded cytoplasm and pycnotic nuclei. Complete loss of the muscle cell nuclei occurred by 128 hr and the ability to take a cytoplasmic stain was lost after 144 hr. Pavementing and cellular exudation from the larger vessels (Fig. 9) and congestion of the smaller blood sinuses in the Leydig cell area below the muscle were noticeable after 24 hr.

Pus accumulated in the necrotic muscle fiber areas by 40 hr and was prominent after 64 hr. An extensive cellulitis, confined to the adductor muscle, was noted in most oysters after 88 hr. The leucocytes present in these lesions were usually necrotic with pycnotic nuclei, whereas the blood cells congesting the surrounding area appeared normal and viable. One lesion at 358 hr appeared to have a band of elongate leucocytes with round nuclei at the periphery of the lesion.

The collagenous connective tissue of the adductor muscle fragmented between 152 and 168 hr and many muscles did not possess any collagen after 216 hr as shown with Mallory's trichrome stain. As early as 312 hr in some cases,

the muscle may become a liquified mass, lacking any recognizable cell structures or color. However, it persisted as a coagulated, necrotic mass until the termination of the experiment.

The visceral ganglia and the nerves below the adductor muscle became necrotic after 40 hr. They continued to undergo necrotic changes with faded, vesicular cytoplasm and pycnotic nuclei until 358 hr when only shadowy cell outlines remained and there was karyorrhexis of the nuclei and nucleolus.

The kidney was necrotic as early as 40 hr with hypertrophied epithelial cells possessing karyolytic nuclei (Fig. 8). The kidney epithelium fragmented and sloughed from its basement membrane after 168 hr and may be completely eliminated as early as 200 hr.

Most of the gill tissue remained normal throughout the experiment, although some portions of the gills were usually congested and slightly necrotic after 56 hr. These necrotic changes appear to follow the normal pattern of postmortem decomposition of this tissue (Sparks and Pauley, 1964), but appeared to be accelerated somewhat by the turpentine injections.

There was a heavy congestion and necrosis of the Leydig cells in the rectal area by 168 hr. The epithelial cells of the rectum were hypertrophied between 184 and 256 hr, after which the epithelium became ulcerated and, in many instances, the epithelial layer was lost after 296 hr.

When the area above the palps of oysters injected in the adductor muscle was studied, a number of vacuolated, brown pigment cells containing three or four nuclei were observed in the Leydig cell area (Fig. 10). Their function is not known, but Stein and Mackin (1955) noted that similar pigment cells, apparently lacking vacuoles, were common in oysters infected with *Dermocystidium marinum*. They thought these pigment cells may be important in fat metabolism. These vacuolated cells were not observed in earlier laboratory experiments by Pauley and Sparks (1965), but they may be a product of certain conditions as is the case of the giant cells observed post-mortem in oysters (Sparks and Pauley, 1964).

Control Oysters

Upon gross examination, all control oysters, whether injected in the connective tissue or in the adductor muscle, appeared normal through the first 104 hr. After this time interval, 22 of the controls injected in the adductor muscle developed an opaque white or yellow discoloration around the site of injection.

Control oysters injected in the connective tissue generally appeared normal in histological preparations, although some individuals developed an edema of the gonadal area and mantle in the vicinity of the injection 16 hr after treatment. After 80 hr, a few control oysters exhibited a very light leucocytic infiltration and congestion of the small blood sinuses in the area of injection. No other recognizable pathological conditions were observed in the control oysters. The gonadal ducts of many of the control oysters were infiltrated with leucocytes resorbing the sex products by phagocytosis (Fig. 11). This resorption

process is normal (Katkansky and Sparks, 1966; Kennedy and Battle, 1964) and should not be mistaken for an inflammatory reaction.

Upon microscopic examination, control oysters injected in the adductor muscle appeared normal in all respects except for localized areas of congestion in the small blood sinuses 32 hr after injection.

DISCUSSION

The congestion observed in the area of injection in the control oysters was probably due to mechanical trauma induced by insertion of the hypodermic needle into the oyster's tissues. However, it appears that this mechanical damage is not capable of evoking an acute inflammatory reaction such as that initiated in the two groups of experimental oysters injected with turpentine.

Both of the experimental groups of oysters injected with turpentine exhibited a similar sequence of pathological changes in the adductor muscle. However, these events occurred somewhat later in the oysters injected in the connective tissue area than in those animals challenged in the adductor muscle. This indicates that the turpentine was not localized in the connective tissue and spread from the Leydig cell region to the adductor muscle.

The pathologic events observed in the connective tissue of the group injected with turpentine in the Leydig cell area were not observed in the connective tissue of the oysters injected in the adductor muscle. The turpentine remained more localized in the adductor muscle, indicating that the adductor muscle has more capacity to restrict an injurious agent than the connective tissue.

These and previous experiments (Pauley and Sparks, 1965) have indicated that the oysters may possess the ability to successfully combat a toxic substance such as turpentine. However, if it gains entry to the blood stream, the turpentine may be spread throughout the oyster's body, causing widespread necrosis of vital tissues, which may eventually result in the death of the oyster, although the latter did not occur within the time limits of the present investigation.

When cells are injured or destroyed and chemical substances within these cells are released into the surrounding tissues, the first phase of the inflammatory process, called the cellular response, is initiated. This phenomenon occurs in both invertebrates and vertebrates and the exact substance responsible is not known, but has been termed "necrosin" by Menkin (1949). The injured cells lose their ability to function properly; this is one of the five cardinal signs of inflammation in vertebrates. The other signs are redness, swelling, heat, and pain.

Redness is one of the first observable signs of inflammation in vertebrates and is caused by an increased number and stasis of erythrocytes in the vicinity of the injury. The oyster does not exhibit any sign of redness during its inflammatory process, due to the lack of erythrocytes. The oyster also lacks a lymphatic system and lymphocytes. Therefore, the leucocytes or amoebocytes play the major role in the defense mechanism of the oyster. Apparently there

are two major types of white blood cells, the hyaline cells and the granular cells (Takatsuki, 1934; Galtsoff, 1964). The latter are the most easily observed and probably are the most important cell type involved in the inflammatory response of the oyster, due to their active phagocytic ability.

Swelling of an inflammatory area is usually observable as a soft, pliable tumorous mass in vertebrates and manifests itself histologically as an edematous area, heavily congested and infiltrated by cellular exudate. Tumorous swellings were not typical in the experimental oysters, but this phenomenon was observed as a white protruding mass on the adductor muscle of a few animals. A general swelling of the adductor muscle was also observed in more than half of the oysters killed after 112 hr. Virtually the same features observed histologically in vertebrate swellings are seen in both the Leydig cell area and the adductor muscles of the turpentine injected oysters, with the exception that no red cell exudation occurs.

Heat is a feature of inflammation usually occuring only after a surface wound in warm-blooded vertebrates (Florey, 1958). This is due to the fact that the surface of the body usually has a lower temperature than the interior. Inflammation causes blood to pass more rapidly and in a greater amount from the interior of the body to some superficial part and this tissue becomes warmer than adjacent normal areas. Since the oyster's blood is at a uniform temperature throughout the animal, which is the same as its ambient temperature, and is not under pressure as is the blood of a vertebrate, heat, as observed in warm-blooded vertebrates, is probably not found in oysters during inflammation. However, true inflammation does take place in the total absence of heat in cold-blooded vertebrates such as frogs (Metchnikov, 1891). It is therefore probable that true inflammation takes place in this molluscan animal.

The exact reason for pain in an inflammatory area is not known, but it seems most likely that it results from pressure on the nerve endings caused by swelling. Since the tissues of an oyster do become swollen during inflammation and this animal does have nerve endings in many parts of the body, pain is a potential phenomenon after any injury. However, the oyster does not possess a central nervous system such as that found in vertebrates and only two pairs of major ganglia are present. It is therefore doubtful that this mollusc can feel pain associated with inflammation in the same sense as vertebrates.

When comparing inflammation in vertebrates and a similar process in the oyster, which we prefer to also call inflammation, it must be kept in mind that the oyster has a different type of circulatory system and lacks many of the specialized types of blood cells found in vertebrates. Because of these differences, these two processes are not and cannot be identical. However, the processes that occur after injury in the oyster are remarkably similar histologically and follow a similar sequence to those observed during inflammation in vertebrates.

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Annual Growth Cycle, Growth Potential, and Growth Compensation in the Bluegill Sunfish in Northern Indiana Lakes[1,2]

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ABSTRACT

Eight lake populations of the bluegill sunfish (*Lepomis macrochirus*) with widely varying growth rates exhibited a surge of growth in the spring followed by a progressively declining growth rate in late summer and autumn. The growth rate declined as age increased; in no case did the growth of an older age group exceed that of a younger age group in the same year. Increase in length was estimated from marginal growth of scales collected at various times throughout 1962 and 1963.

The beginning of the growing season, assumed to correspond in time with the formation of the annulus, was estimated to average April 8 in 1962 and April 26 in 1963. The time of annulus formation was observed in one lake by collecting scales when the mark was appearing, and in the others it was estimated by extrapolation of a regression between marginal scale growth and time. The end of the growing season, or the time when 90% of annual growth had been achieved, came on September 10 in 1962 and on September 27 in 1963. The length of the growing season varied among the lakes and between years in the same lake. The range was from 98 to 189 days with an average of 152 days. In one lake the season was a month longer in 1963 than in 1962, but this difference was not evident in the others.

The annual rate of growth and the length of the growing season were related. Populations with a rapid growth rate had a longer growing season than those with a slow growth rate. A long season was typified by a somewhat earlier time of annulus formation than a short one and by a considerably longer period of growth in the late summer and autumn.

All populations had the same growth potential as judged by weight increment of group III fish during the first month of the season. The first month's increments were 12.6, 12.9, and 13.9 g for populations with rapid, intermediate, and slow annual growth rates respectively. The population with the shortest growing season and the lowest annual growth had the greatest increment during the first month.

The strong relationship between size and the time of annulus formation suggested a possible mechanism of growth compensation. Since the smaller fish of a year class begin to grow earlier than do their larger companions, growth compensation may result from the advantage in time gained by the smaller group, assuming that the growing seasons of it and the faster growing members of the cohort end at the same time. Most of the mechanisms offered heretofore have depended upon a difference in the time of hatching between two groups of fish.

Consideration is given to an explanation of the annual growth cycle in terms of temperature, photoperiod, and the possible influence of growth hormone at different times of the year.

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INTRODUCTION

THIS RESEARCH was undertaken with these objectives in view: (1) to measure the length of the growing season of the bluegill sunfish (*Lepomis macrochirus*) in eight northern Indiana lakes; (2) to learn the amount of variation in the growing season among lakes; (3) to investigate the possible relationship between the annual rate of growth and the growing season. The work was stimulated by Beckman's (1943) finding that 85% of expected growth had been achieved by July among bluegills in Pasinski Pond, Michigan. Since the annulus had formed late in April, the growing season was not much longer than 3 months. The pond, therefore, "lay fallow" for 9 months of the year as far as fish production was concerned. Fish production, or the amount of organic matter formed during a specified period of time regardless of whether or not it survives to the end of that time (Ricker and Foerster, 1948), is usually expressed as an annual rate. The "production year" in temperate climates, however, is not a full 12 months in duration, and may be very short indeed if Beckman's results are generally applicable.

Variation in the growing season is usually associated with latitude because annual growth is greater at lower than at higher latitudes. The difference is attributed to differences in climate, primarily temperature. Hubbs and Cooper (1935), who noticed an increased dwarfing of the longear (*Lepomis megalotis*) and green (*Lepomis cyanellus*) sunfishes toward the north in the State of Michigan, correlated the decrease in size with the mean annual temperature and the average number of days from the last killing frost in spring to the first killing frost in autumn. Bennett (1937) estimated the growing season of the largemouth bass (*Micropterus salmoides*) in Louisiana to be 9 months, Nebraska 5–6 months, and Wisconsin 4–5 months, and called attention to the progressive reduction in the annual growth rates from south to north. The growth of the largemouth and smallmouth (*Micropterus dolomieui*) bass in Tennessee was related by Jones (1941) to the agricultural growing season. Beckman (1943) contributed to the idea that the growing season was dependent upon latitude by determining the time of annulus formation in several warmwater species in the State of Michigan. The annulus was completed by mid-May in the southern third of the lower peninsula, by the first half of June in the upper two-thirds of the lower peninsula, and by the end of June in the upper peninsula. These dates varied roughly with mean monthly air temperature.

The emphasis placed to date on the influence of latitude on the length of the growing season tends to obscure the possibility that differences may exist among localities in the same geographic area which are not explained on the basis of climate. If individual variation is great, the "production year" will have to be determined in each study area. Only a small amount of information has been acquired on this question. Deason and Hile (1947) described differences in the growing season among closely situated localities in the same year. The growing season of the kiyi (*Coregonus kiyi*) ended at different times in different parts of Lake Michigan. Kiyis from the Fox Islands and Port Washington continued growth after mid-August, but those from Manistique

ceased growing in late July. Stroud's (1948) results apply to year-to-year variation in Norris Reservoir, Tennessee. The growing season of three species of black basses and the black crappie (*Pomoxis nigromaculatus*) began about a month earlier in 1945 and 1946 than in other years of a 10-year period beginning with 1936.

For the last 20 years the assumption has been made, without much supporting evidence, that the annual rate of growth depends upon the length of the growing season. Van Oosten (1944), Carlander (1948), Eschmeyer (1950), and Stroud (1948) have all assumed that growth was greater if the growing season was longer. The proposition needs to be examined critically since the growth rate of an individual could conceivably be great enough during a short period of time to surpass the increment achieved by the same individual growing slowly over a long growing season. If the assumption is true, however, the factors that influence the growing season may be identified, and as a consequence, production rate could be placed under more precise control. Hile's (1936) work on the lake herring (*Coregonus artedii*) of northeastern Wisconsin revealed that the Trout Lake population had the poorest growth and shortest growing season, and the Clear Lake population the best growth and longest season. Muskellunge and Silver lakes had intermediate growth rates and growing seasons of intermediate length.

Hodgson (1925), the first to measure the growing season, established that the period of growth of the Atlantic herring (*Clupea harengus*) off the coast of England extended from April to October by examining the growth of scales collected at intervals throughout the year. Hodgson's method was employed in the present study. The beginning of growth was assumed to correspond with the time of annulus formation and the distance from the last annulus to the margin was used to estimate the current year's growth. Direct observations were made on the time of annulus formation in one of the eight lakes, and the first appearance of the annulus was estimated for the remaining seven by a regression between marginal scale growth and the date of collection. The date corresponding to 90% of total growth achieved during the year was arbitrarily selected as the "end" of the growing season. To date most of the work on the length of the growing season has been done with a method developed by Hile (1936). He estimated the growth of a particular year class of lake herring in several lakes of northeastern Wisconsin from the time of annulus formation to the time of capture as a proportion of total growth for the year. Total growth was calculated for that year class from scale collections made in years subsequent to the year in question. This indirect method has been used by Spoor (1938) with the white sucker (*Catostomus commersoni*), Hile (1941) with the rock bass (*Ambloplites rupestris*), Deason and Hile (1947) with the kiyi, and Smith (1956) with the lake herring.

Using the multiple sampling method of Hodgson, it was learned that the difference between the longest and shortest growing seasons in the sample was nearly twofold and year-to-year differences amounted to as much as 1 month. The average of all measurements of the growing season in northern

Indiana was 152 days. Annual growth rate and growing season were closely related. The faster growing populations had the longest growing season, the slowest growing populations had the shortest growing season, and the lakes with intermediate growth fell between. Despite the differences in annual growth rates among the eight populations, growth potential was the same as judged by the weight increment achieved during the first month after annulus formation. The research also opened the possibility of following the food turnover at intervals throughout the growing season, and yielded an explanation of growth compensation based on a difference in the time of annulus formation among fish of different sizes of the same year class.

In presenting the results upon which these findings are based, a selection of my materials was made to save space. Seasonal growth curves for all eight lakes were analyzed, for example, but only four are presented in the text. The lakes chosen for illustration are representative; other lakes fell into the same pattern. Seasonal growth was expressed in either length or weight, whichever served the purpose most appropriately.

LAKES AND GENERAL METHODS

Lakes

Bluegill scale samples were collected from eight lakes: Maxinkuckee (area, 668 ha; max. depth, 26 m) and Pretty (34 ha; 23 m) in Marshall County; Carr (26 ha; 13 m), Ridinger (47 ha; 13 m), and Spear (16 ha; 13 m) in Kosciusko County; and Crooked (83 ha; 33 m), High (40 ha; 15 m), and Sylvan (233 ha; 11 m) in Noble County. These lakes were selected for sampling on the basis of their geographic distribution and the rate of growth of the fish. They are spread over most of the northern Indiana lake district, and the results should represent the length of the growing season in the latitude between 41° and 41°30″ north in the midwestern United States.

The eight lakes were selected from 60 Indiana lakes in which Ricker (1942) had studied the growth of the bluegill. Since the length of the growing season and the annual rate of growth might be related, the selection included populations with rapid, intermediate, and slow growth. A quick comparison of growth rates can be made from lengths achieved during the present study at the second and third annuli in the various localities. Sylvan, Carr, and Maxinkuckee are classed as lakes in which bluegills grow rapidly; the fish reached 75–123 mm fork length at the time of the formation of the second annulus, and 121–156 mm at the third. Populations in Spear and High lakes have intermediate growth; length ranged from 64–70 mm and from 114–123 mm at the formation of the second and third annuli respectively. Ridinger, Crooked, and Pretty lakes have bluegills with a slow growth rate; lengths at the second annulus varied from 53–68 mm, and at the third they varied from 80–107 mm.

Each lake retained the same position in the ranking in both 1962 and 1963. The Sylvan Lake population was among the most rapidly growing recorded in the United States and Pretty Lake was among the slowest (Carlander, 1950, 1953). The difference in length achieved in these two lakes by the second

annulus was over twofold, the average lengths being 53 mm in Pretty Lake and 123 mm in Sylvan Lake.

Scale Collections

Scales were taken from a few fish collected in traps, but the vast majority of samples were obtained from the fishermen's catch. The catch was usually sampled from a centrally located boat livery, but two lakes lacked a livery; here contacts were made at scattered points around the shoreline. Scales were sampled from the left side of each specimen at the tip of the pectoral fin just beneath the lateral line, a region recommended by Regier (1962). Although the scales were all taken from the same position on the body, they were not located precisely enough to be regarded as key scales.

The lakes were visited regularly during the summer. The eight lakes were regarded as four pairs. Collections were made on each pair for alternating half-monthly periods from the first week in June to the first week in September in 1962 and 1963. A minimum sample of 100 scales was taken during each collecting period. This number was easily exceeded in most lakes, but in two the quota was reached only by persistent work. Infrequent collections were made in early spring, fall, and winter. Every lake was visited in winter, but ice fishing was so unproductive on three of the eight lakes that insufficient samples were collected.

The year was divided into 14 periods for the computations. Each 2-week interval in summer was regarded as a period. The rest of the year was subdivided into monthly periods except for the months of ice-cover — December through February — which were treated as a single period.

Processing the Scales and the Data

A total of 11,463 scale samples were taken, 5831 in the first year of the study and 5632 in the second. Most of the samples were handled in assembly-line fashion during the summer soon after they were collected. The fall and winter samples were prepared as they accumulated. Three to six scales, usually four, from each sample were impressed into cellulose acetate strips of 0.51-mm thickness. The impressions were made with a roller press copied from the design of Smith (1954). An Eberbach projector (40×) was used in the summer to obtain measurements from the scales, and a scale-projecting machine (60×) designed from the description provided by Van Oosten et al. (1934) was used in the winter.

Each sample was identified by an assigned number. The collecting date, sex (if determined), lake, county, and collector were also recorded. Length from the tip of the lower jaw to the fork of the tail was measured in millimeters and weight was measured in grams. Scale measurements in millimeters included the distance from the focus to each annulus in the anterior field of the scale, the distance from the last annulus to the margin, and the scale radius.

Annuli on bluegill scales are clearly marked by "cutting over" on the lateral fields and by the start of widely spaced circuli in the anterior field.

The former is a better criterion than the latter. Annuli are known to form occasionally during the winter in the Indiana lakes, but this was not observed during the present study. Annulus formation occurred in March, April, and May.

As many as 20 pieces of information could be obtained from each scale sample, or a possible total of nearly 250,000 data to be sorted and analyzed. Two computer programs were designed for the IBM 709 (Gerking, 1965) at the Research Computing Center of Indiana University for this purpose. Each program consisted of two parts. The first program yielded the relationships of scale radius to body length and of length to weight. The second computed the average length at the time of formation of each annulus, termed "length at each age." This program also gave the average length increment achieved from the time of annulus formation to the time of collection in each of the 14 periods of the year, hereafter called the "current year's growth."

BODY-SCALE RELATIONSHIPS

The body-scale relationships, based on the scale radius as the dependent variable, were calculated for each of the eight lakes. The computer print-out tabulated the average scale radius for each 5-mm interval of fork length between 92 mm and the maximum length achieved, usually 222 mm. Linearity between the variables was tested by inspection after plotting on graph paper; none of the populations exhibited a decided departure from a straight-line relationship. The print-out also yielded a regression relating anterior scale radius to fork length, the standard deviation of the regression coefficient, and the intercept on the length axis which was extrapolated from the regression.

The intercepts on the length axis varied from year to year and from lake to lake (Table I). Year-to-year agreement was reasonably good, although the Sylvan Lake population exhibited a striking change from 10.1 mm in 1962 to 3.5 mm in 1963, and Spear Lake changed from 4.3 mm in 1962 to 14.1 in 1963. No explanation was found for these differences. Lake-to-lake differences were greater, however. The intercept was considerably smaller in Ridinger Lake fish than in the others; the value of 1.2 mm for Ridinger Lake contrasted sharply to Carr Lake which had the highest value of 18.5 mm. Regier (1962) noted differences in the intercept of about the same magnitude as reported here in bluegill populations of 24 farm ponds near Ithaca, New York.

The position of the length intercept was studied carefully to choose a value which could be used to back-calculate lengths at different annuli and to compute the current year's growth. Ricker (1942) selected 20 mm as the value to be used in the equation proposed by Lee (1920) and stated that any value close to the true intercept would be satisfactory for comparing lengths at different ages in various lakes. Regier (1962) demonstrated that small differences resulted when values back-calculated from the mean of a number of independently determined length intercepts were compared with those back-calculated from a value which departed appreciably from the mean. The

TABLE I. Intercepts on length axis as estimated from extrapolations of the body length–scale radius regressions. Average scale radius was used for each 5-mm length interval in calculating the regression for each of eight lakes.

Lake	1962		1963	
	Average length intercept (*mm*)	Number of length intervals	Average length intercept (*mm*)	Number of length intervals
Sylvan	10.14	21	3.45	13
Carr	15.20	20	18.46	25
Maxinkuckee	13.76	19	13.46	19
Spear	4.34	24	14.08	23
High	17.80	19	12.00	17
Crooked	13.60	17	11.68	17
Ridinger	1.92	17	1.18	22
Pretty	8.45	13	11.98	21
Weighted mean	11.43		11.25	

average intercept in Regier's 17 ponds with the most reliable data was 16.5 mm, corrected from total length to fork length. The weighted mean values in the Indiana lakes in the present study were 11.4 mm in 1962 and 11.3 in 1963. When the low values from Ridinger Lake were eliminated, the weighted average intercepts were 12.6 mm in 1962 and 12.9 mm in 1963. A 12-mm figure was selected for back-calculation in this study. The Lee equation then becomes:

$$L_n = 12 + \frac{L_r - 12}{S_r} S_n$$

where L_n = fork length at each annulus, S_n = distance from scale focus to each annulus, L_r = fork length at capture, and S_r = scale radius.

GENERAL DESCRIPTION OF SEASONAL GROWTH

Sylvan Lake and Pretty Lake were selected to demonstrate seasonal growth in populations with different growth rates and a different range of age groups (Fig. 1). A comparison of the growth of fish during long and short growing seasons is provided by data for Carr and Ridinger lakes (Fig. 2). The shape of the growth curves agrees closely despite these differences.

Sylvan Lake is represented by more points on the growth curves than the others. A special effort was made to collect samples at short time intervals in this lake, and the Sylvan population is used to illustrate several important concepts later in this report. Systematic visitations began in the first 2 weeks of June, 1962. Spring collections started the next year in mid-April. Among the four lakes, winter samples were taken in Sylvan Lake in both years, and in Pretty Lake in 1963. No winter samples were collected in either year from Carr

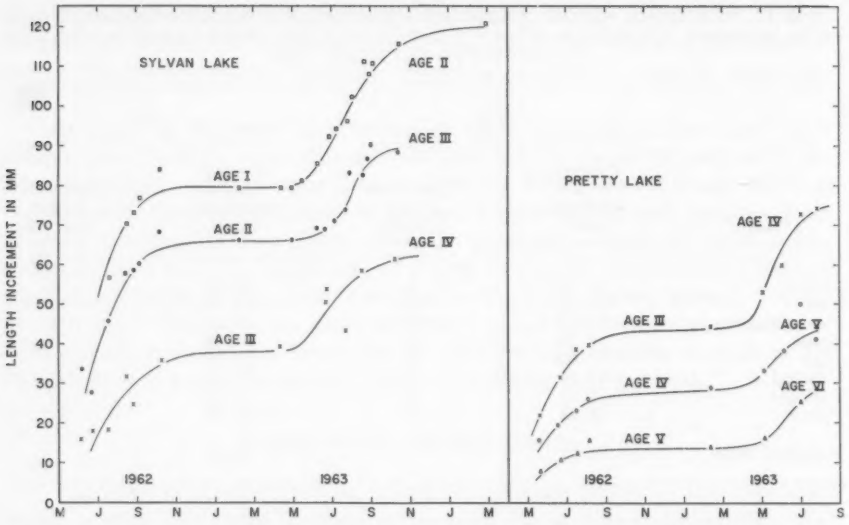

FIG. 1. Seasonal gains in length of two bluegill populations with different growth rates and different age groups in the fishermen's catch. The abcissa is divided into bimonthly intervals beginning with May. The ordinate is the length gain of various age groups at several collecting dates beginning in the spring of 1962.

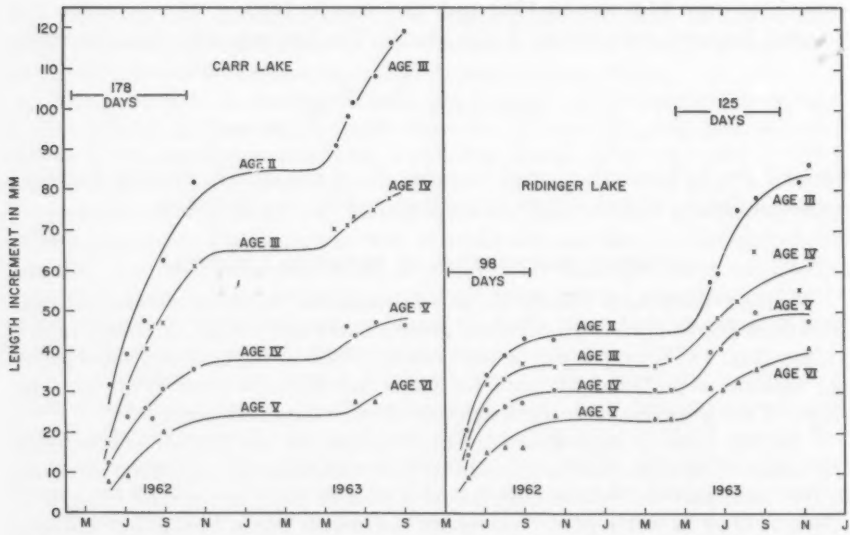

FIG. 2. Seasonal gains in length in two bluegill populations exhibiting growing seasons of different lengths. The abcissa is divided into bimonthly intervals beginning with May. The ordinate is the length gain of various age groups at several collecting dates beginning in the spring of 1962.

and Ridinger lakes although both were visited several times. Of the remaining four lakes, Crooked and Spear supplied abundant winter samples; High was poor in this respect; and Maxinkuckee yielded well in 1963, but no samples were taken in 1964. Sampling throughout the year is, therefore, not equally represented in all localities, but the shape of the growth curves agrees closely regardless of the sampling differences.

Length increments of the current year's growth were plotted directly against the date of collection in 1962. The 1963 increments were added to the maximum gain accomplished the previous year before plotting, in order to present gain in length continuously over a 2-year period. The time of collection was plotted either midway between the beginning and end of a collecting period or, if the collection was made on a single day, the actual date was shown. The average length increments are not based on equal numbers of fish, and, therefore, are not equally reliable. Generally speaking, each value derived from a younger age group is based on more measurements than that for older age groups. The decrease in numbers with age explains why the plotted points for older fish exhibit considerably greater scatter about the curves than do the points for the younger groups. The curves were drawn by inspection to represent as nearly as possible the course of seasonal growth for the various age groups in the different lakes.

The general shape of the seasonal growth curves is the same in all stocks regardless of the rate of growth or of the length of the growing season. The growth of each age group in each lake in each year began about May 1, and rose very sharply from the time of annulus formation. After a period of rapid growth lasting from 6 to 8 weeks, the growth rate declined to a low level by September or October. The curves suggest a semilogarithmic relation between growth and time, but they cannot be described by a common mathematical function. Each curve is individualistic and probably results from a close interaction between the bluegill populations and their environments. The individualistic quality of the seasonal growth curves is also expressed in the differences that are apparent in the length of the growing season from lake to lake in the same year, and from year to year in the same lake. For example, the growing season was obviously longer in Carr than in Ridinger in 1962, but the growing season in Ridinger Lake lengthened substantially in 1963. These differences are examined more carefully later.

The curves were drawn as if a small increase in length occurred during the winter months, but evidence for winter growth was not clear. Twelve comparisons of length increments calculated from samples obtained in February or March were made with those calculated from October or November samples. The comparisons were drawn from Crooked, Sylvan, and Maxinkuckee lakes and involved age groups ranging from I to VI. Six of the winter increments were greater than the autumn increments, whereas four were in the reverse order and two exhibited no difference between autumn and winter. No age trend was found. The Sylvan Lake samples offered an opportunity to compare fall (October 6 and 7, 1962), winter (February 9, 1963), and spring (April 11,

1963) increments, beginning with annulus formation in 1962, in group I and group II fish. Group I increments were 84.3, 79.7, and 84.2 mm in the order named; group II values were 68.1, 66.0, and 62.6 mm in the same order. None of the differences between successive values were statistically significant. Similar comparisons were made between winter and spring increments in several age groups from Crooked, Maxinkuckee, and Spear lakes. None of these produced statistically significant evidence of growth from the time of ice cover in February and March to the time of annulus formation in the spring. In summary, a slight amount of growth was made between autumn and midwinter in a small majority of comparisons, but they were nearly counterbalanced by differences in the opposite direction. No growth was demonstrated between midwinter and spring.

The most striking feature of the seasonal growth curves is the regular decline in length increments among increasingly older fish. Not once did the total growth of an older age group outstrip that of a younger age group in the same year. If the fact that the growth rate of fishes declines with age needs to be underscored, the data here should serve.

The course of seasonal growth in the bluegill agreed with the results of past work on a number of species although other investigators have not usually sampled throughout the year. Three different bases have been employed previously: marginal growth of scales collected at intervals during the year; average lengths of fish caught at intervals during the year; and marginal scale growth at the time of capture as a fraction of the total amount of growth expected to be achieved during the year. Since the results provided by these methods are similar, no distinction is made among them in the following discussion.

Sprugel (1954) described a short growing season in the bluegill population of McFarland Pond, Iowa. Young-of-the-year had made most of their growth by late June, and little or no growth took place among group I and group II fish after late July. The annulus began to appear on the scales during the first week in April, making the growing season about 4 months. This season was much shorter than that reported by Bennett et al. (1940) in the bluegill population of Fork Lake, Illinois. Annulus formation began about the first of April, and growth continued at a fairly regular rate for 7 months until late October. These differences in the length of the growing season are striking, but the growth pattern was similar in both populations; a spurt of growth soon after the time of annulus formation was followed by a gradual decline until only a negligible amount could be detected.

Ricker and Foerster (1948) charted the growth of age 0 sockeye salmon (*Oncorhynchus nerka*) in Cultus Lake, British Columbia, during its growing season from June through November. The curve followed a sigmoid form. Growth rate was slow early in the season, increased to a maximum, and then leveled off as winter approached. The seasonal growth curve of the lake trout (*Salvelinus namaycush*) has also been interpreted as sigmoid by Lawrie (1952) and by Fry (1953) in Lake Superior and Lake Huron where the growing season

is about 6 months, and by Kennedy (1954) in Great Slave Lake where the season is only 3 months. Sigmoid growth curves have also been drawn by Kennedy (1953) for the Great Slave Lake whitefish (*Coregonus clupeaformis*), by Smith (1956) for Lake Michigan lake herring, and by Dryer and Beil (1954) for the Lake Superior lake herring. Several of the growth curves rise abruptly without an initial period of slow growth. The early period of slow growth is lacking when there has been no opportunity to collect material early in the season and when the measurements have not been sensitive enough to detect small changes. This explanation applies to the work by Hodgson (1925) on the Atlantic herring, Cooper (1953) on brook trout (*Salvelinus fontinalis*) in Michigan streams, Eschmeyer (1950) on the walleye in Lake Gogebic, Michigan, and Larimore (1957) on the warmouth in Illinois ponds.

For the most part, our data are not extensive enough to chart accurately the early spring growth. There are indications that growth slowly increases to a maximum, but this period is apparently very short. The sigmoid growth curve has been described most often in cold-water species in localities where temperatures rise more slowly than in Indiana. A slowly increasing growth rate was drawn in the transition between the 1962 and 1963 growing seasons because it seems reasonable that the spring surge would be preceded by a period of slow growth during the time when the fish are reentering more favorable conditions.

BEGINNING OF THE GROWING SEASON

Sylvan Lake

The beginning of growth in the spring is assumed to correspond with the formation of the annulus. If this assumption is correct, the time when growth begins can be determined directly by collecting scales at short intervals during the period when the annulus appears on the scales. These collections were made from Sylvan Lake in 1963, but it was not convenient to do so for the others. Indirect methods of determining the time of annulus formation were devised for those lakes where direct observation was lacking. The data collected from Sylvan Lake provided a "test case" for judging the accuracy of these indirect methods.

Direct observation yielded information about the proportion of fish which had formed the annulus between collecting dates. The annulus first appeared on the scales of group II fish between April 27, 1963, when none possessed a year mark, and May 11, when 30% had developed a recognizable check on the scale (Fig. 3). All individuals had well-developed annuli by June 8, a month from the time when the first specimens began their spring growth. On May 18, 50% of group II (total in group II, 309 fish) were estimated to have formed an annulus, and the same proportion of group III (total in group III, 68 fish) had an annulus by June 5, a difference of 18 days.

Two indirect methods were devised and tested with the Sylvan Lake materials to establish the time of annulus formation more precisely in stocks where frequent collections could not be made. The first is based on the number

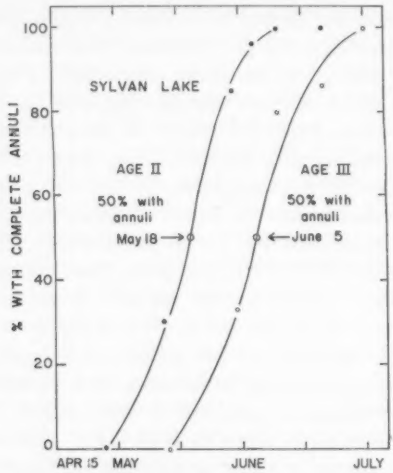

FIG. 3. Percentages of two age groups of Sylvan Lake bluegills with complete annuli at different times in 1963.

of circuli between the last annulus and the margin. The beginning of the formation of the annulus could be recognized before this mark completely encircled the scale. The circuli between the radii on the anterior margin of the scale are most often concave. The annulus, however, extends from radius to radius as either a straight or a convex line. Under either condition the distance is greater between the last circulus of the previous season of growth and the annulus than the distance between adjacent circuli near the annulus on either side. The annulus could be recognized when only two circuli had formed between it and the scale margin. Under ordinary scale reading conditions an annulus in this position might not have been recognized. The identification of newly forming annuli was done on scale impressions under a binocular microscope with a zoom lens and optimal lighting.

When annulus formation was first noticed in group II on May 11, 4 of a total of 56 fish had two circuli between the annulus and the margin, and 11 had three. The weighted average number of circuli was, then, $(4 \times 2) + (11 \times 3)/56 = 0.73$. The average number of circuli in all of the samples taken until June 20–23 was calculated in this fashion (Fig. 4). The average number of circuli on scales of group II rose slowly at first and then very rapidly, reaching 12.4 by June 20–23. Between May 11 and May 30, the number of circuli increased 0.21 per day. This figure rose to 0.38 per day between May 30 and June 5 and remained the same until June 23.

The annulus appeared about 15–20 days later in age group III as compared with group II, and the rate of circulus formation was much slower. The data for the older of the two age groups were so scanty that all samples from May 30 to June 6 and from June 8 to 23 were lumped to obtain more reliable samples.

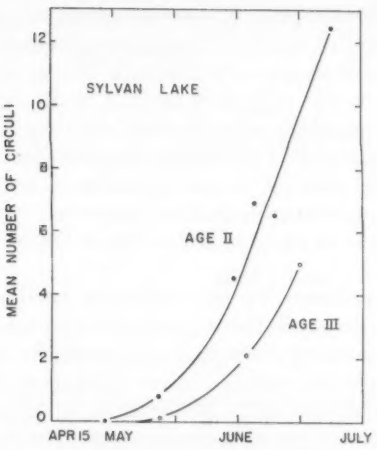

FIG. 4. Increase in the mean number of circuli in Sylvan Lake bluegills in 1963.

Variability in the number of circuli between the annulus and the margin was exceedingly great from the time of the May 30–31 samples. On those dates the number of circuli of 121 scales of group II bluegills ranged from 0 to 22 and had a weighted mean of 4.7. The range was nearly as great during the last days of sampling, June 20–23, when the number varied from 3 to 25 and averaged 12.4. The high values of 22 and 25 might be suspected to represent the number of circuli laid down since the annulus of the previous year rather than the current year except for the fact that the frequency distributions were nearly continuous. The distributions of group III circuli were nearly as broad.

The second indirect method employed to determine the time of annulus formation was based on the distance between the last annulus and the margin rather than circulus counts. This distance was positively correlated with the number of circuli in that area of the scale. A test of correlation between the two variables (65 pairs of measurements on group II fish collected between June 5 and 8, 1963) yielded a correlation coefficient of 0.746 ($P < 0.01$). The distance from the last annulus to the margin was accordingly substituted for the number of circuli in the computations to follow.

From the circulus counts (Fig. 4), the date when the first individuals began to exhibit annuli was estimated as May 5. This date can be compared with a similar date extrapolated from a regression between the distance from the last annulus to the margin and time. The May 11 sample of age group II was avoided because this point was at the lower inflection of the sigmoid curve when the scale was growing slowly. The other four points plus one in early July exhibited no departure from linearity and were used to compute the regression. The intercept on the abcissa was May 3. The time when the annulus first began to appear in group III was about May 15 on the basis of the

circulus counts, and it was May 19 by the regression technique. The correspondence between the two methods is exceptionally good for both age groups and lends a considerable degree of confidence to the estimation of the time of annulus formation by the regression method in the other lakes.

The regression of marginal measurements and time is similar to the method recommended by Backiel (1962) for determining the time of annulus formation. His method takes into account a correction for slower growth of the scale immediately after the annulus forms than somewhat later in the spring. The period of slow growth is so short in the northern Indiana bluegill populations that it was disregarded.

The degree of confidence in the regression method depends upon the number of degrees of freedom in the computation and the scatter about the line of least squares. The present method is not extremely accurate since only a few collecting dates could be employed before a departure from linearity became severe. The 95% confidence limits of the time when the annulus began to appear on the scales are broad as a consequence. The majority of regressions in the discussion to follow are based on five or more collecting dates, but a considerable number are drawn from only four. Despite the broad confidence limits, the method has the advantage of estimating the time of annulus formation from collections made subsequent to the event. The date could be gained otherwise only by frequent collections during the period corresponding to growth resumption.

Other Lakes

The distance from the last annulus to the margin was tabulated for selected dates on each lake, and the individual measurements were averaged. The means were plotted against the date of collection to learn whether or not a departure from linearity was evident by inspection. A regression was calculated on the data that appeared to be linear, and the remaining information was discarded. Ridinger Lake collections offer an example of the procedure (Fig. 5). Growth of the scale was linear with time from June 1 to July 5, 1962, after which the growth rate declined markedly. This characteristic was evident in age groups II, III, IV, and V. Only the age groups III and V are illustrated in the figure to simplify presentation. The mean distances from the last annulus to the margin on four collecting dates between June 1 and July 5 were used to estimate the time of annulus formation by regression. This date, by extrapolation, was April 29 for group III and May 4 for group V.

Individual regression computations for different age groups in different years supplied 45 estimates of the time of annulus formation. The estimates varied considerably — from March 9 in Lake Maxinkuckee in 1962 to May 19 in Sylvan Lake in 1963. Slightly over half (23 of 45) of the estimates were in April and most of these were concentrated between April 10 and 20. The 8 March dates were scattered through the month, and the 14 May dates were all between May 1 and May 20. The first appearance of the annulus averaged April 17. Three possible factors causing this variability were explored: effect

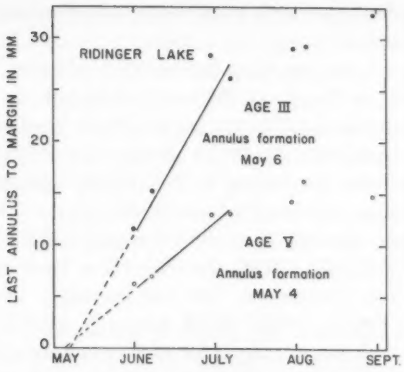

FIG. 5. Extrapolations (broken lines) of the first appearance of the annulus from the linear relation between time and the distance from the last annulus to the margin of scales of two age groups of Ridinger Lake bluegills, 1962. Departure from linearity appears after July 5.

of age, year-to-year variation, and effect of size within an age group. The first two factors are discussed in the subsections immediately following. An analysis of the effect of size within an age group on the time of annulus formation produced a new explanation of growth compensation. This analysis appears in a separate section of the paper.

EFFECT OF AGE

The computation of confidence limits was advantageous in making judgments about the statistical reliability of differences in the time of first appearance of the annulus determined by the regression method. For example, the 16-day delay in annulus formation of group III from Sylvan Lake in 1963 as compared with group II was not statistically significant. The 95% confidence limits of the May 3 date of group II (April 21 and May 15) were overlapped by those for the May 19 date of group III (April 20 and June 7). This result contrasted with an evident difference between the two age groups when marginal circuli counts and the percentages of fish with and without annuli were compared during the period of growth resumption (see Figs. 3 and 4).

The time between the lower and upper confidence limits in the Sylvan Lake example cited above varies from 3 to 7 weeks, and this range was about average for all of the estimations. Under these conditions, a difference in the time of annulus formation had to be substantial before it became statistically significant. This lack of sensitivity of the regression method accounts in part for the result that 24 of 29 comparisons between age groups showed no statistically reliable differences. The conclusion is reached that the regression method, as used here, is useful for the purpose of estimating the time when growth

begins but is not sensitive enough to differentiate the relatively small effect of age on annulus formation.

The generally held opinion that the annulus of older fish forms later than in younger specimens is based on the consistency of the observation from a variety of sources. Sample size has not always been large enough to be convincing in individual comparisons, however. Hodgson's (1925) tables showing the relation of age to annulus formation in the Atlantic herring were drawn from relatively small samples, although he concluded that "...the older fish have a tendency to begin their growth later than the young fish." Small samples were also characteristic of Stroud's (1948) work on three bass species and the black crappie in Norris Lake, Tennessee, but the tendency described by Hodgson was clearly evident. Frey's (1942) work on carp agreed with Hodgson and Stroud but younger fish were caught in different lakes than the older ones, and a comparison between them might have been confounded by their origin.

Later work has been more satisfactory in this respect as exemplified by the results of Smith (1956) on the Lake Michigan lake herring. The percentage of each age group possessing annuli was compared on a series of sampling dates taken during the time of annulus formation. The percentage of each age group showing an annulus increased as the season progressed and the younger age groups completed the annulus before the older age groups. The information is too scanty for some age groups on some sampling dates for statistical comparison, but a chi-square test of independence such as that between age groups III and IV on May 26, 1948, is an indication of delay of annulus formation associated with age:

	With annuli	Without annuli	Total
Age group III	45	96	141
Age group IV	20	90	110
Total	65	186	251

Chi-square = 5.93 with 1 *d. f.* ($P = <0.001$)

The same type of analysis was performed on McFadden's (1959) brook trout data with the same result, but Bailey's (1964) samples of the American smelt were too small to permit the comparison although the effect of age was apparent in the percentage values. Where the data were adequate, no results contrary to the above were obtained.

Year-to-Year Differences

Comparisons of the differences in the time of annulus formation in the same age group in different years were made in the same manner as has been described. Two-thirds of the 21 possible comparisons had confidence limits that overlapped, and the remaining 7 were scattered among five of the eight lakes.

The distinction between years was not clear-cut, but in 62% of the total number of comparisons the time of annulus formation was earlier in 1962 than in 1963. That this tendency may reflect the true situation is suggested by the fact that the annulus appeared earlier in 1962 in six of the seven comparisons in which differences between the years could be distinguished statistically. For example, both comparisons available for Crooked Lake indicated significantly earlier annulus formation in 1962. For group III the date of April 9, 1962 (95% limits, March 30 and April 20) contrasted to April 30, 1963 (95% limits, April 24 and May 5). The group IV comparison was made between April 24, 1962 (95% limits, April 17 and April 30) and May 13, 1963 (95% limits, May 4 and May 22).

Although the evidence is not decisive, the tendency for an earlier date for the beginning of growth in 1962 was sufficiently strong that a separate computation of the first appearance of the annulus was made for each year. The mean dates of annulus formation were acquired by averaging the dates for the various age groups in each lake after they were weighted by the number of measurements used to compute the regressions from which they were established.

END OF THE GROWING SEASON

There is no point in time in the autumn that can be termed the "end" of the growing season because the growth rate declines very gradually. From a practical standpoint, however, a time can be selected arbitrarily beyond which a very small percentage of total annual growth is achieved. To select the time, a point was chosen on the seasonal growth curve which represents the total increase in length for the year. Various percentages of this value were found, and the dates corresponding to the percentage values were read from the graph. For example, the increment in 1962–1963 for age group I fish in Sylvan Lake was 80.5 mm (see Fig. 1); 90% of this value is 72.5 mm; and the date corresponding to 72.5 mm was August 24. Values of the annual increment (50, 80, 90, and 95%) were calculated for each age group in each lake in each year where the data were available (Table II).

The date when 90% of the total increment had been achieved was selected as the end of the growing season, because the growth rate slacked off rapidly at this time. Taking all lakes into consideration, a month (between the mean dates of August 11 and September 13) was required for the fish to grow from 80 to 90% of their total length increment. Approximately an equal amount of time (between September 13 and October 17) was needed to add the amount between 90 and 95% of the total length increment.

No confidence limits could be set for the dates established above and, as a consequence, possible differences among age groups could not be tested. Simple inspection of the data indicated that the end of the growing season was not affected by age, and the age groups were lumped to obtain averages for each year.

TABLE II. Number of days after first appearance of annulus when various percentages of annual growth had been achieved by the bluegill in eight northern Indiana lakes. Values represent averages for all age groups.

Lake	Year	Percentage of annual growth			
		50	80	90	95
Sylvan	1962–63	79	127	150	173
	1963–64	70	117	156	181
Spear	1962–63	75	127	169	214
	1963–64	77	133	167	214
Crooked	1962–63	55	106	144	182
	1963–64	49	108	155	187
Ridinger	1962–63	38	73	98	122
	1963–64	61	106	125	164
Carr	1962–63	86	128	152	176
Maxinkuckee	1962–63	104	149	189	236
High	1962–63	86	128	152	176
Pretty	1962–63	67	109	139	178
Mean		71	119	152	186

LENGTH OF THE GROWING SEASON

The length of the growing season varied among the lakes and between years in the same lake (Table III). The Ridinger Lake population in 1962 had the shortest growing season of 98 days and Maxinkuckee had the longest of 189 days in the same year. The mean length of the growing season for all lakes was 152 days. Among the four lakes where the growing season could be estimated for both 1962 and 1963 only Ridinger exhibited a distinct difference between the years, amounting to nearly a month. Although the dates when growth began and when 90% of the total increment was achieved were different in the 2 years, the length of the growing season in Spear, Crooked, and Sylvan lakes differed by no more than 11 days between 1962 and 1963 — certainly within the range of error of the method.

The length of the growing season remained almost constant from year to year in Spear, Crooked, and Sylvan lakes because the end of the growing season varied with the time of annulus formation. When the annulus appeared earlier in 1962 than in 1963, as in Crooked and Sylvan lakes, the growing season ended in mid-September of 1962 as compared with the first week in October of 1963. The reverse was true in Spear Lake where the 1962 annulus was delayed a few days later than in 1963; the 1962 growing season extended about 2 weeks later into the fall as compared with 1963. In six of the eight lakes the annulus formed earlier in 1962 than in 1963, a point that was discussed earlier. The difference in time varied from a few days in Crooked and Carr lakes to a month or more in Sylvan, Pretty, Maxinkuckee, and High lakes. The mean dates were April 8 in 1962 and April 26 in 1963, a difference of nearly 3 weeks. The mean dates for the end of the growing season were September 10, 1962 and September 27, 1963.

TABLE III. Length of the growing season of bluegill sunfish in eight northern Indiana lakes.

Lake	Year	Beginning	End[a]	Duration (*days*)
Ridinger	1962	May 2	Aug. 8	98
	1963	April 24	Sept. 14	125
Spear	1962	April 14	Sept. 30	169
	1963	April 6	Sept. 19	167
Crooked	1962	April 25	Sept. 16	144
	1963	May 3	Oct. 5	155
Sylvan	1962	April 9	Sept. 16	150
	1963	May 6	Oct. 8	156
Pretty	1962	April 16	Sept. 2	139
	1963	May 10	–	
Maxinkuckee	1962	March 12	Sept. 17	189
	1963	May 8	–	
High	1962	March 20	Aug. 19	152
	1963	April 19	–	
Carr	1962	April 11	Oct. 5	178
	1963	April 14	–	
Mean	1962	April 8	Sept. 10	152
	1963	April 26	Sept. 27	151

[a]When 90% of the annual growth had been achieved.

The length of the growing season was correlated with the annual rate of growth. Maxinkuckee, Carr, and Sylvan lakes which had the greatest growth rate averaged 170 days (measurements from both years). The lakes with intermediate growth, Spear and High, averaged 163 days in the growing season. Pretty, Ridinger, and Crooked lakes with the slowest growth rates of all had a 134-day growing season. The difference in length of the growing season among the three groups of lakes was associated with an average earlier annulus formation in the fast-growing populations, April 15, and populations with an intermediate growth rate, April 7, as compared with the populations exhibiting poor growth, April 27. The end of the growing season for fast-growing populations extended beyond that of the slow-growing populations. Maxinkuckee, Carr, and Sylvan averaged September 27 (disregarding the year in which the determination was made); Spear and High averaged September 12; and Pretty, Ridinger, and Crooked averaged September 9.

GROWTH POTENTIAL

Fish growth in nature is extremely variable and the question arises as to whether differences in the environment or in heredity are responsible for the major share of this variability. Generally speaking, the consensus of opinion

favors environmental factors on the basis of evidence of improvement in growth after a decrease in population density by winterkill (Beckman, 1941, 1942) and by poisoning (Bennett, 1962). Indeed, the success of fish management, especially in ponds, depends heavily upon the predictable and rapid response that fish make to a decrease in density. Nevertheless, hereditary factors cannot be entirely discounted since an improvement in growth has been accomplished in hatcheries by selective breeding. This work is better known in trout (Dinsmore, 1934; Shellington, 1934; Donaldson and Olson, 1957), although some evidence has been acquired in the largemouth bass (Prather, 1951). The question is particularly pertinent in the present work because the Indiana populations were sampled from glacial lakes formed about 12,000 years ago. Although the genetic constitution of the populations may have been influenced by artificial stocking, and some movement between lakes which are connected, the possibility remains that the growth rates may have been affected by inbreeding.

The evidence from the eight lake populations favors the interpretation that environmental factors outweigh heredity in governing fish growth. Length was converted to weight, according to length–weight equations, for the analysis leading to this conclusion (Fig. 6). Annual growth of group III fish was not associated with the rate of growth during the early spring and early summer. For example, annual growth was much greater in group III Sylvan Lake bluegills than in those from Ridinger even though the slopes of the curves of spring and summer growth up to August are nearly the same. The difference between the lakes is explained by the very substantial increase in weight made by the Sylvan fish after the time when the Ridinger population had practically ceased growing. The Ridinger Lake population had, therefore, the same potential for growth as that of the most rapidly growing population in our sample, but it was not sustained over as long a period of time.

The beginning of the growing season should be the most sensitive time of year to compare the growth potentials of the eight lake populations because food is then at a high level (Gerking, 1962), and the fish are exhibiting the spring surge of growth. Consequently, increments in weight during the first month of the growing season (Table IV) were determined from the season growth curves. Averages of the group III increments for the entire growing season placed the lakes in the same ranking as averages for all age groups: Sylvan, Carr, and Maxinkuckee (rapid growth) averaged 73.4 g; Spear and High (intermediate), 59.5 g; Ridinger, Crooked, and Pretty (slow), 42.1 g. But this sequence was not followed in the averages of the first month's increments. Lakes with rapid and intermediate growth had the same increments (12.6 and 12.9 g respectively) but those with slow growth averaged about 1 g more (13.9 g). Ridinger Lake, which had the greatest increment for the first month (16.7 g), had the smallest increment for the entire growing season (36.0 g). The instantaneous growth rates during the first month are given for reference. They represent the rate of growth expressed as a fraction of the original weight. The instantaneous rates are related inversely to size at the beginning of the growing season.

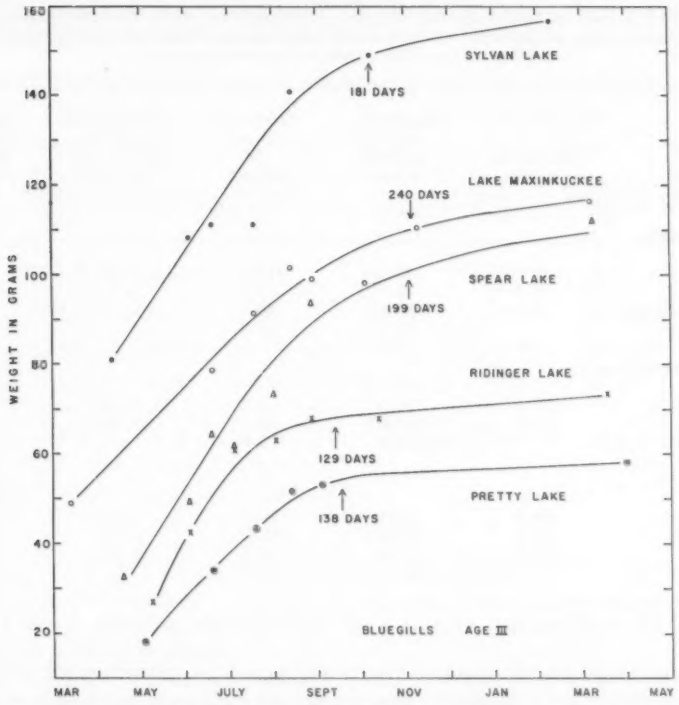

FIG. 6. Gain in weight of group III bluegills in 1962–63. Length of the growing season is indicated by arrows on the diagram. The five populations represent rapid (Sylvan and Maxinkuckee), intermediate (Spear), and slow (Ridinger and Pretty) growth rates.

The fact that the first month's increments in weight of the slow-growing populations are as great or greater than those of the fast-growing populations argues strongly for the interpretation that all of the eight populations have about the same potential for growth. If this assumption is true, then the variability in growth observed in the eight lakes is explained by factors operating in the environment and not in the hereditary makeup of the populations.

Increase in weight during the period of growth depended principally on the length of the growing season. The fast-growing group III bluegills had a growing season of 199 days; populations with intermediate growth averaged 175 days; and the growing season of slowly growing populations was 146 days. This conclusion had been reached earlier by comparing length measurements in a much less detailed manner than is presented here.

FOOD TURNOVER

The seasonal growth curves provide an opportunity to compare estimates of the food turnover during the summer. The estimates were based on the same

TABLE IV. Growth in weight (grams) of group III bluegills in eight lakes of northern Indiana in 1962. Classification of the lakes on the basis of rapid, intermediate, and slow growth was done after taking all age groups into consideration.

Lake	Beginning weight	Increment during growing season	Increment during first month	Instantaneous growth rate during first month	Length of growing season (*days*)
Rapid growth					
Sylvan	79.5	67.5	15.0	0.18	181
Carr	42.6	96.9	12.4	0.26	178
Maxinkuckee	48.0	55.9	10.5	0.20	240
Mean		73.4	12.6		199
Intermediate growth					
Spear	29.0	70.3	15.0	0.41	199
High	28.5	48.8	10.8	0.33	152
Mean		59.5	12.9		175
Slow growth					
Ridinger	26.5	36.0	16.7	0.49	129
Crooked	22.2	53.7	15.0	0.52	171
Pretty	15.9	36.6	10.1	0.50	138
Mean		42.1	13.9		146

weight data used in the analysis of growth potential. Monthly increments of growth in weight were obtained from the curves, and each increment was converted to daily gain in milligrams of nitrogen by assuming that protein was 17% of the live weight and that nitrogen made up 16% of protein. The formula $y = -3.02 + 0.421x$, where x = the daily food turnover in milligrams of nitrogen and y = daily weight gain in milligrams of nitrogen was used to estimate the amount of food consumed during each month of the growing season. The formula was developed from feeding experiments on 26 g bluegills (Gerking, 1955a) and was applied here without regard to the size of the fish. Efficiencies of food conversion for fish larger than 26 g are probably overestimated, and the resulting food turnover values are too small as a result. The estimates offer a reasonably reliable basis for comparison although none is as accurate as is desirable.

Comparisons of the monthly gain in weight, efficiency of protein utilization for growth, and monthly protein turnover were made between Sylvan and Pretty lakes, representing populations with rapid and slow growth rates respectively (Table V). Age group III was used for this analysis as it was for the growth potential. The decrease in monthly growth increment during the growing season, evident in both populations, was characteristic of all lakes except Carr. Growth increased in midsummer in Carr Lake over that in the spring. In Sylvan Lake the increments declined from an initial value of 15.0 to 7.5 g/month during the last full month of a 181-day growing season. The growth of the

TABLE V. Estimated monthly increments in weight, efficiencies of protein utilization for growth, and protein turnovers for average individuals in group III bluegills of Sylvan and Pretty lakes, Indiana, in 1962.

Sylvan Lake				Pretty Lake			
Month	Monthly increment (g)	Efficiency (%)	Protein turnover (g)	Month	Monthly increment (g)	Efficiency (%)	Protein turnover (g)
First	15.0	35.2	7.25	First	10.1	31.7	5.42
Second	14.5	34.2	7.20	Second	9.5	31.1	5.21
Third	14.5	34.2	7.20	Third	8.8	30.5	4.93
Fourth	13.0	33.5	6.59	Fourth	6.5	27.8	3.96
Fifth	7.5	29.0	4.38	Remainder (14 days)	1.7	22.0	1.32
Remainder (18 days)	3.0	25.2	2.02				
Total			34.64	Total			20.84

Pretty Lake population also declined in a regular fashion from 10.1 to 6.5 g/month in a 138-day season.

The slightly higher efficiencies in Sylvan Lake than in Pretty Lake reflect the more rapid rate of growth in the former population. The values were highest in the first month when weight was being added at a more rapid rate than at any other time during the growing season. The maximum efficiencies were 35% in Sylvan and 32% in Pretty Lake. The similarity adds strength to the argument that the two populations have the same potential for growth even though their annual growth rates are considerably different.

The protein turnover was greater in Sylvan Lake, 34.6 g, than in Pretty Lake, 20.8 g, because of a larger growth increment and a longer growing season. The combination of these two factors influenced the food turnover in all of the eight lakes. The turnover in the lakes with rapid growth (Sylvan, Carr, and Maxinkuckee) averaged 37.6 g; in those with intermediate growth (Spear and High) it was 31.4 g; and in those with slow growth (Ridinger, Crooked, and Pretty) it was 22.5 g. Ridinger Lake, which had the lowest annual growth increment, 18.2 g, had the greatest protein turnover, 8.1 g, during the first month of the growing season, surpassing even that of Sylvan Lake (7.3 g).

A MECHANISM FOR GROWTH COMPENSATION

Growth compensation is a term reserved for the tendency of slow-growing yearlings to grow more rapidly later in life than their faster growing companions of the same year class. The result is a progressive reduction in the size range

among older individuals. Growth compensation sets in immediately after the first year in some families such as the Coregonidae or it may be delayed in others such as the Centrarchidae. Hubbs and Cooper (1935) discovered in Michigan a positive correlation between first- and second-year growth, "reverse growth compensation" or "depensation" as it has been called, in the longear sunfish (*Lepomis megalotis*), pumpkinseed (*Lepomis gibbosus*), bluegill, and a pumpkinseed × bluegill hybrid. Hile (1941) found the same phenomenon in the rock bass of Nebish Lake, Wisconsin, but was able to describe growth compensation in the original sense of the term in age groups beyond group IV. Scott's (1949) results on the rock bass of Tippecanoe River, Indiana, were essentially similar to Hile's.

The theoretical explanations for growth compensation have been reviewed by Smith (1956). They date back to Hodgson's (1929) idea that the difference in length between two groups of fish with growth curves of the same shape would naturally tend to become reduced with time, if the groups were hatched at different times during the year. Hile (1941) refined the idea to include the specific case of the rock bass which had a sigmoid growth curve. Ford (1933) offered an explanation based on growth curves that are dissimilar in shape. Smith expanded on Ford's idea by presenting evidence that size achieved at the start of a growth period determines the amount of growth to be made during that period. These explanations are all reasonable inasmuch as experience has demonstrated that fish do hatch at different times in the same year and that the growth curves of individual fish differ from one another.

The present suggestion for explaining growth compensation is based on a time differential as above, but on a difference in the time of annulus formation, not on a difference in the time of hatching. It will be described in three steps. First, it is necessary to present a brief description of growth compensation itself because it has not yet been reported for the bluegill. Next is a demonstration of the effect of size on the time of annulus formation, and lastly is described the manner in which the time differences of annulus formation can account for growth compensation.

The ability of slower-growing members of a cohort to overtake partially the faster-growing members was investigated in age group IV of Spear Lake, collected in 1963. The Spear Lake population was chosen because it offered a large sample of relatively old fish, an essential feature of the analysis if the growth characteristics of the bluegill resembled those of the rock bass — depensation in the second year followed sometime later by a compensation. Scott's (1949) method of describing growth compensation was used whereby regression coefficients were calculated between the length achieved at the time of formation of the first annulus and the increments of growth in succeeding years. The coefficient of + 0.5754 was statistically significant when a 't' test was made between the relation of first-year growth and the increment between the first and second annulus ($P = < 0.001$); the slow-growing fish of the first year were also the slow-growing group of the second. When the first-year increments were compared with those between the second and third annuli, the coefficient,

−0.1736, changed sign and was not significant ($P = 0.200$). A strong growth compensation appeared, however, when the fourth-year increments were related to first-year growth. The regression coefficient was negative, −0.7278, and statistically significant, ($P = 0.001$). Thus, the typical centrarchid pattern was followed. Depensation in the second year of life, creating a broad range of sizes, was counterbalanced in the fourth year by a strong tendency to reduce the variability. The third year of life represented a transition between these opposing trends. Growth compensation was calculated in only one of the eight lakes because the object was to learn whether or not the phenomenon could be identified in the species, not to explore it exhaustively.

The group II Sylvan Lake bluegills exhibited a pronounced effect of size on the time of annulus formation. Sylvan Lake was used for the test because it was the only population from which was obtained a complete series of samples that extended through the whole period when the yearly mark was being laid down. The method of Frey (1942) was employed whereby the mean calculated length at the time of annulus formation for those fish with the yearly mark was compared with the mean length at the time of capture for fish with no such mark. Three comparisons were made on samples collected May 11, May 30–31, and June 5–6, and in all three the fish that had formed the annulus were shorter ($P = < 0.015$) than those that had not (Table VI). The differences were 8.3, 13.3, and 11.7 mm on the respective dates.

TABLE VI. Average fork lengths (mm) of group II fish with and without annuli in Sylvan Lake, Indiana, in 1963. The length of the fish with annuli is that at the time of annulus formation; the length of those without annuli is that at the time of capture.

	Average fork length			
	With annulus	Without annulus	Difference	P ('t' test)
May 11	136.00	144.33	8.33	0.015
May 30–31	140.50	154.88	13.28	0.005
June 5–6	154.22	165.89	11.67	0.005

From the shape of the seasonal growth curve it is obvious that the fish forming the annulus first will have a tremendous jump on those that form the annulus later. The advantage is so great that it is unlikely to be overcome by the end of the growing season. Even a slight advantage in the time when growth starts might confer a decided advantage with respect to the amount of growth that could be achieved during the year.

The growth curves of age group IV collected in 1962 and 1963 in Spear Lake, where compensation was demonstrated to have taken place, serves as a practical example of the possible effect of the time of annulus formation on subsequent growth. The 1960 year class illustrates the effect, assuming that

those fish which formed late annuli grew in exactly the same manner as those forming early annuli (Fig. 7). The time of first appearance of the annulus was April 6 as determined by the regression method. If the course of annulus formation was similar to that in Sylvan Lake, described earlier, the new mark appeared in the population during the course of 1 month. To be on the conservative side, the late formers of annuli were considered to be 3 weeks later than the early ones. The curves now have exactly the same shape, and on September 3 when 90% of growth had been achieved for those which had formed the annulus early, the two groups differed by 4.0 mm. Because the growth rate is declining drastically after this time, much more than the original 3-week disadvantage is required to close the gap. The difference is never entirely made up, of course, even if the curves are extended indefinitely. A 6-week extension of the growing season is required before the difference is reduced to 1.0 mm, an amount that might be considered negligible. No such radical difference in the end of the growing season between two groups of fish appears in our data,

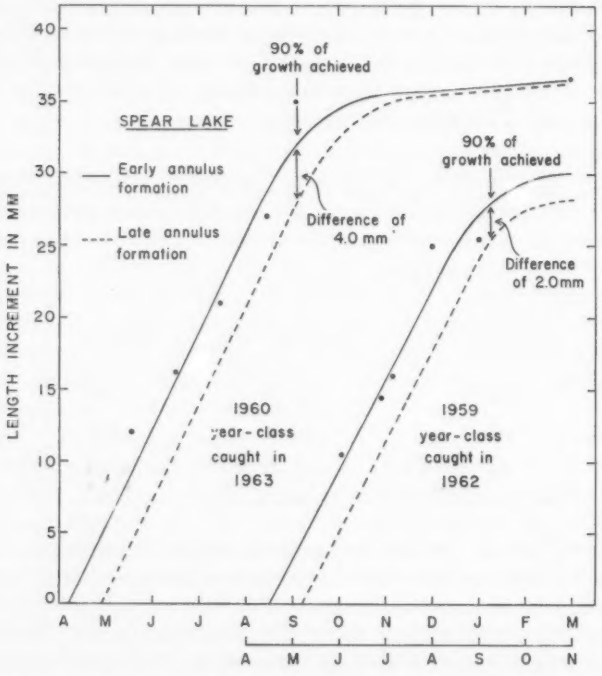

FIG. 7. A mechanism for growth compensation based on differential time of annulus formation. For the 1960 year class the difference in length between "early formers" and "late formers" is inconsequential if the growing season of the latter extends beyond the time when that of the former ends. The curves for the 1959 year class demonstrate that the difference in length between the two groups is never made up if the growing season of both groups ends at the same time.

however. More likely is the prospect that the growing season ends at about the same time in a given age group, regardless of the time of annulus formation. This alternative is illustrated by the curves for the 1959 year class of Spear Lake (Fig. 7). Here the curves parallel one another beyond the 90% point, and a 2-mm difference between the early and late formers would persist until growth began the next spring.

This explanation of growth compensation is adequate only if (1) the growth of the whole age group slows to a negligible rate at the same time and (2) the difference in time of annulus formation is in the neighborhood of a month. At the moment, no assurance exists that the whole year class stops growing at the same time. No satisfactory solution to this question can be proposed until variability in the end of the growing season can be measured.

If the fish that forms annuli early start growing less than a month earlier than those that start growth late, the difference between their body lengths at the end of the growing season is too small to consider seriously. A number of curves of different shapes were plotted in a manner similar to Fig. 7 to reach this conclusion. In this regard it should be remembered that many species form the annulus over a much longer period than 1 month. For example, the lake trout of Lake Michigan forms its yearly mark over a period of 4 months (Cable, 1956) and the lake herring from the same lake requires 2 months (Smith, 1956).

How generally this explanation of growth compensation can be applied cannot be predicted. It depends, of course, upon how widely the effect of size upon the time of annulus formation is distributed among taxonomic groups. The literature is not helpful in this regard. Frey's (1942) conclusion from a study on the age and growth of carp in Wisconsin that small fish of either sex form annuli earlier than larger fish of the same sex and age is not upheld in all of the subsequent work. Smith (1956) had extensive evidence to confirm Frey's finding on lake herring of Green Bay, Lake Michigan, which was later supported by William R. Dryer for lake herring in Lake Superior (personal communication). But McFadden (1959) found that the reverse was true in a brook trout (*Salvelinus fontinalis*) population of Lawrence Creek, Wisconsin. A smaller proportion of small fish of age groups I and II had completed annulus formation by April 12–16, 1956, than larger ones. The issue is confused further by the report (Hansen, 1937) that results similar to those of Frey were obtained in the white crappie (*Pomoxis annularis*) in Illinois in 1936 and those similar to McFadden's were found in 1935. Chronological age of the crappies was disregarded by Hansen and he reported that scale-edge absorption might have obscured the results in 1935.

Depensation in the second year in centrarchid species remains an enigma. Differences in time of annulus formation of fish of different sizes do no more explain it than do differences in time of hatching unless, as Hile (1941) points out, there is a definite inflection of the growth curve just after the second annulus forms. Hubbs, and Cooper's (1935) reasoning that size in the first year confers a competitive advantage in the second still cannot be improved upon.

Aside from this special circumstance, an explanation of growth compensation based on early and late annulus formation is as plausible as one based on early and late hatching. In fact, the two are not mutually exclusive, and one may accentuate the effect of the other.

Also remaining unanswered is the question of why shorter bluegills develop annuli earlier than do longer specimens. The data could be interpreted either as a real time difference between the two groups or only as an apparent difference. If the time difference is real, it is due to some ability of shorter fish to respond more rapidly than longer ones to rising temperatures, or the presence of abundant food in the spring, or some combination of these and other factors. It is doubtful, however, that "physiological aging" effects, based on differences of only a few millimeters in size, would be expressed in so refined a manner.

An apparent difference in the time of annulus formation could be explained in the following manner. Both length groups may begin to form the annulus at the same time, but the mark may become recognizable on the scale a few days to a few weeks later in the longer group than in the shorter one. "About 4 mm must be gained before the annulus is completed," according to Richard O. Anderson (personal communication). Since the rate of increase in length declines as fish increase in size, the possibility should be considered that more time is required for the longer group to exhibit a recognizable annulus than is required for the shorter group. This interpretation is supported by the results of Swift and Pickford (1965). They state, "These results show that a 3% increase in body length was required before any increase in scale width was recorded. Body length increments greater than 3% resulted in a proportional increase in scale width." A 3% increase in length takes place more quickly in shorter bluegills than in longer ones.

No sound basis exists upon which to choose among these alternatives at this time. The question might be resolved if annuli could be produced at will on fish reared in the laboratory or if large numbers could be kept under observation in outdoor enclosures in a manner similar to that of Anderson (1959).

INTRINSIC AND EXTRINSIC FACTORS IN THE ANNUAL GROWTH CYCLE

This description of the progress and duration of seasonal growth in a limited geographic area of northern Indiana has emphasized the need for research on several fundamental problems which have heavy implications for fish management. The cause of the variability in the length of the growing season is well worth investigating by itself, but it assumes added importance since the duration of growth is a major factor governing the total length and weight that can be achieved during the year. According to the present study, fish may be produced in neighboring lakes for lengths of time varying between 4 and 8 months. These populations may have the same growth rate in the spring, but their length and weight at the end of the growing season depends upon how long growth is maintained.

The problem of identifying the factors contributing to variability in seasonal growth has been narrowed only slightly by the present work. Possibly most important is establishing the same growth potential in the eight populations. If inbreeding can be eliminated as a significant influence on the rate of growth of natural populations, then attention can be directed toward other possible intrinsic and extrinsic factors that may be responsible. Differences in climate and morphometry can be ruled out in the series of lakes under consideration. Carr, Spear, and Ridinger are located in the same county, and each has the same maximum depth; yet they have decidedly different growth rates and growing seasons. Area was not correlated with either the rate of growth or the length of the growing season. Lake Maxinkuckee with the longest growing season and a rapidly growing population is 14 times larger than Ridinger Lake with the shortest growing season and a slowly growing population, but this relationship between size of lake and rate of growth was not apparent when the whole series of lakes was considered.

Although temperature is generally agreed to affect growth, no direct correlation between these variables has been demonstrated generally in natural situations. Coble (1966) has reviewed the effect of temperature on growth of the yellow perch (*Perca flavescens*). His data indicated a definite relation between growth of the scale from the annulus to the margin and the temperature at 7 m where the fish were living in South Bay, Ontario. But other information in the literature did not agree with this simple interpretation. A hypothesis was developed to the effect that whereas growth is dependent upon temperature, other factors may mask or modify the relationship. This would explain why the effect is present in one lake but not in another.

No success was achieved with the data in an attempt to link the beginning and end of the growing season with temperature changes. The results are reported here in brief form. Sylvan and Crooked lakes were investigated carefully because they contrast sharply in morphometry and productivity. The maximum depth of Crooked Lake is 33 m and that of Sylvan is 11 m. The former is mesotrophic, whereas the latter is extremely eutrophic as a result of domestic pollution. The populations in these lakes formed the annulus at the same time in 1963; the average date was May 3 for all age groups in Crooked Lake and May 6 in Sylvan. This agreement existed despite mid-April surface temperatures that were 3.3 C lower in Crooked Lake (7.8 C) than in Sylvan (11.1 C). The water warmed more rapidly in the deep lake and by May 1 it was the same as that of the shallow one (12.7 C). This contrast in the rate of warming of the surface water continued throughout the period from mid-April to mid-May, the critical period when temperature would be expected to exert its greatest influence (Crooked, 0.276 C/day; Sylvan, 0.110 C/day). Temperatures at 5–6 m were slightly lower in both lakes, but the differences between the lakes and the rate of warming were practically the same as at the surface.

At the end of the growing season the surface waters were warmer in Crooked Lake (19.7 C on October 5) than in Sylvan (17.4 C on October 8). Again, the temperatures at 5–6 m were slightly lower, but the difference between the

lakes was almost the same as that of the surface water. Growth in Crooked Lake, therefore, began at the same temperature but ended at a higher temperature compared with Sylvan Lake.

The measurements of oxygen distribution, calcium carbonate distribution, and primary productivity were not helpful in defining the beginning or end of the growing season. Primary productivity was measured in 1963 by Robert G. Wetzel (personal communication), and he reported a higher but less stable rate of algal photosynthesis in Sylvan Lake than in Crooked. The lack of correspondence in the amount and stability of primary production between the lakes is even more striking than the other limnological conditions, but the annulus formed at the same time.

As reported earlier, six of the eight lakes had an earlier annulus formation in 1962 than in 1963. Formation was concentrated in mid-March to late April in 1962 as compared with mid-April to the first week of May in 1963. Yet, average March air temperatures were definitely cooler in the first year as compared with the second by an average of 2.8 C (1.0 C in 1962; 3.8 C in 1963). A total of 987 degree days (number of days below 65 F times number of degrees) was exhibited in 1962 and 801 in the year following, according to the records of six weather stations situated close to the lakes (Climatological Data, 1963). If it is assumed that the warmth of the surface water parallels that of the air, this difference in March temperatures is the reverse of what might be expected if water temperature itself is regarded as the primary stimulus for the development of the yearly mark. Possibly the rate of warming is a more important factor. Since April air temperatures were almost the same in the two years (9.0 C in 1962; 10.0 in 1963), the rate of warming was more rapid in 1962 when the annulus formed earlier.

Perhaps temperature should not have been expected to provide the answer. Deason and Hile (1947) cast some doubt on this factor as influencing the beginning of the growing season in the kiyi in Lake Michigan because there is no warming of the deep water where they live as there is in shallower water. In fact, the kiyi experiences little more than 2 C temperature range throughout the year, yet the species forms annuli and undergoes a seasonal growth cycle similar to that reported here. Light and food were suggested as possible dominating influences for this species.

Photoperiod has not been regarded as an important factor influencing seasonal growth until recently. Although the influence of light on the pituitary gland and, in turn, its influence on the reproductive cycle in fishes is well known (Pickford and Atz, 1957), the effect of light on growth has not been demonstrated. According to the current interpretation, light stimulates the release of a factor by the hypothalamus which triggers the release of gonadotropin by the pituitary. A growth-hormone-releasing factor has also been identified in higher vertebrates. Swift (1961) satisfied himself that photoperiod played no role in explaining the seasonal growth cycle of the brown trout (*Salmo trutta*). Experiments conducted in hatchery ponds and in light-tight,

constant-temperature aquaria showed no correlation between day length and specific growth rate.

The photoperiod issue has been raised again, however, by Gross et al. (1965) with convincing positive results, utilizing the green sunfish (*Lepomis cyanellus*) as the experimental animal. Swift had used constant day lengths of different photoperiods in his experiments. Gross et al. used the same technique in light-tight tanks and learned that growth was slightly better with a 16-hr day than with an 8-hr day. The effect of light on growth was enhanced greatly, however, by increasing or decreasing the day length. Increasing the day length from 8 to 16 hrs in 6-week experiments promoted growth whereas decreasing it from 16 to 8 hrs depressed growth to the level achieved in a constant 8 hr day environment. Growth was more closely correlated to food conversion efficiency than to food consumption in these experiments. An explanation of the seasonal growth cycle, according to their interpretation, would involve both temperature and light. Rapid growth in the spring is the result of the synergistic action of both increasing temperature and day length; declining growth in the fall is due to coincident decreasing temperature and day length.

The implication of the pituitary growth hormone in controlling seasonal growth is supported by provocative evidence accumulated by Swift and Pickford (1965) on assays of perch (*Perca fluviatalis*) pituitary glands collected throughout the year. Seven samples of glands were collected from Lake Windermere, England, from April 1961 to February 1962.

The glands were lyophilized and kept frozen in 0.6% NaCl until the material was used for intraperitoneal injections in hypophysectomized male *Fundulus heteroclitus*. The growth response of the killifish indicates that the hormone increased to a peak in July. The effect of other pituitary hormones, such as ACTH and TSH, on growth was not entirely excluded. The time lag between maximal accumulation of the hormone and the high growth rate could not be explained. In August the hormone dropped to very low levels, 10-fold below the resting level, but the growth was still very high. The growing season did not end until October. Even though the time relationships between what is presumed to be cause and effect are not entirely clear, without doubt this work has called attention to variations in the secretion of the pituitary growth hormone as a serious possibility in explaining the seasonal growth cycle. The research is particularly applicable to growth resumption in the spring. The authors stated, "The effect of rising temperature in spring may, therefore, be twofold: the stimulation and production of pituitary growth hormone, and the subsequent facilitation of the ability of the tissues to respond." On the basis of the photoperiod response, it might be added that the stimulation and production of pituitary growth hormone could have been caused by the increasing light as well as temperature.

The photoperiod response and the variability in pituitary growth hormone potency at different seasons both warrant intensive investigation on a number of species since the seasonal growth cycle is common to all temperate-zone fishes. If the results from the green sunfish and perch apply generally, the

explanation of some fundamental aspects of fish growth will have been answered. Procedures are available for studying the effects of photoperiod on growth, but the study of the variations in the hormone will be retarded, unfortunately, until the technique of hypophysectomizing fish becomes more widely mastered. The importance of feeding and the food supply should not be overlooked, however. The growth hormone cannot exert its effect unless the fish are able to find adequate food. The spring peak in growth hormone should correspond to the time of maximum food availability to exert its greatest effect. According to present information, this is the case. Benthos and zooplankton, the food of the bluegill, have been found to be at their peak of abundance in the spring in Wyland Lake, India..a (Gerking, 1962), and reports from many other sources indicate that a spring peak may be expected generally. The decline in both the rate of growth in weight and in the food turnover as the summer progresses may also be due to a combined effect of physiological regulation of growth and a decreasing food supply, but this interpretation of the seasonal growth cycle requires rigorous work in the field and in the laboratory before it can be accepted.

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Serum Proteins and Antibody Production in Rainbow Trout (*Salmo gairdneri*)[1]

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ABSTRACT

Rainbow trout serum was shown to be made up of three major protein components. These three major components did not coincide by electrophoretic mobility or by relative salt solubility with the classic albumin, α-, β-, and γ-globulin separation of the sera of higher animals. A component equivalent to γ-globulin of higher animals was found to be completely lacking in the sera of both immunized and non-immunized rainbow trout.

Specific humoral antibodies in rainbow trout immune sera were found to be contained in the electrophoretically least mobile proteins. These proteins coincided most nearly to the β-globulins and possibly the least electrophoretically mobile α-globulins of higher animals. Salt solubility of the serum proteins containing the specific antibody assisted in this conclusion. The electrophoretically least mobile major serum protein components were found to contain all of the antibody activity. These proteins could be removed from immune serum by 20% sodium sulfate. The assumption was made that *Aeromonas hydrophila* antibodies in immunized rainbow trout blood serum may be made up of a complex of serum proteins with a broad range of salt solubility and electrophoretic mobilities.

Serum proteins of rainbow trout could also be classified as euglobulins or pseudoglobulins. The serum proteins which contained the *A. hydrophila* antibodies were found to be euglobulins.

INTRODUCTION

The chemistry of immunity is a description on a molecular level of the various factors which kill microorganisms, retard their growth, and neutralize their toxic products (Talmage and Cann, 1961). Specific immunity is due to definite protein molecules which are considered to be modified normal globulin (Isliker, 1957).

Poikilothermic animals, being capable of antibody response, must be able to exhibit globulin changes within the blood plasma to allow this response. A knowledge of the plasma proteins of these animals would be desirable to understand the immune response of poikilothermic animals.

Identification of the serum proteins which function as antibody requires the separation of these proteins under the major group of proteins. Sorensen (1925) separated those humal serum proteins insoluble at low ionic strength and *p*H 5.5–6.8 (euglobulins) from those which were soluble at the same condition (pseudoglobulins). Further differential fractionation of human blood serum proteins yielded γ-, β-, and α- globulins and albumins (Kibrick and Blostein, 1948).

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Electrophoresis has been used as a method of demonstrating blood proteins in many animals. Results indicate that certain fishes may be lacking in one or more of the classical protein fractions. The most rapid electrophoretic component of Elasmobranchii differs from that of other animals (Irisawa and Irisawa, 1954). Proteins corresponding to γ-globulin of higher animals is either reduced or lacking in teleost fishes (Engle et al., 1958).

The immunologist must be somewhat aware of the classes of serum proteins as well as certain cellular elements of the blood and other tissues in order to assess immunological change. Serum fractionation by physical methods (salt fractionation and electrophoretic mobility) can be used. Identification of antibody protein among the great number of individual types of protein in such a complex mixture as blood serum, has been the subject of a great deal of literature in the past 20 or more years. Only cursory separation of the serum proteins of teleost fishes has been effected. The results reported here are the first step in the identification of those proteins which have been altered to exhibit antibody function in rainbow trout.

MATERIALS AND METHODS

Information on experimental animals and on many of the experimental procedures are given in a previous paper (Post, 1966).

Normal rainbow trout serum was obtained by bleeding 1000 hatchery-reared rainbow trout. The blood was allowed to clot, the serum was separated following centrifugation, and the sera were pooled. Portions of the pooled sera were used in experimental procedures.

A method of separating serum protein by salt solubility was devised using portions of the 1000-fish composite serum. Dry sodium sulfate was added to 25-ml portions of serum held at 25 C to produce 8, 10, 12, and 14% w/v of the salt. A small precipitate formed at 12 and 14% w/v sodium sulfate and was separated by centrifugation; additional sodium sulfate was added to the supernatant through 16, 18, 20, 22, 24, and 26% of the salt. The supernatant–salt mixture had to be held at 37 C above 22% sodium sulfate to maintain solution. Each precipitate was dissolved in the smallest amount of 0.1 ionic strength *p*H 7.8 disodium–monosodium phosphate buffer necessary for solution. These solutions were dialyzed from 24 to 72 hr in the 0.1 ionic strength phosphate buffer at 4 C. Quantitative protein determination was carried out on each solution of protein by the method of Lowry et al. (1951). Electrophoretic mobility was carried out on each solution using an LKB instrument with a 27-cm field. A Beckman Analitrol was used to quantize electrophoretograms and to produce graphic patterns.

Paper electrophoresis of the successive serum protein precipitates was accomplished using sodium barbiturate buffer (*p*H 8.6) at 250 v and 15 ma for 16 hr. The electropherograms were stained with Bromphenol blue; the running temperature was 20 C. A procedure was devised from these analyses for the separation of rainbow trout serum into the three major protein groups. The least

mobile group was separated by raising the sodium sulfate concentration to 17%. The precipitate was separated by centrifugation and the supernatant was increased to 22% sodium sulfate. The precipitate which formed was separated by filtration. The moderately mobile group of proteins made up the precipitate and the most rapid component remained in the supernatant. The two precipitates were purified by redissolving in 0.1 ionic strength *p*H 7.8 phosphate buffer and by reprecipitating at the desired sodium sulfate concentration (i.e. 17 or 22%). Completeness of separation was demonstrated by means of paper electrophoresis.

Similar procedures were applied to serum of fish which carried agglutinating antibodies specific for *A. hydrophila* in their sera. Sera were separated into three major fractions. Each of the precipitated fractions was reprecipitated and dialyzed for purification. All three fractions were used in agglutination tests to locate the antibody.

Results of these analyses indicated antibody was present in the two least soluble fractions. Therefore, additional sera from immunized fish were treated at levels of sodium sulfate between 17 and 22%. Nearly all antibody was removed from the serum of rainbow trout which had been immunized against *A. hydrophila* by precipitation at 20% sodium sulfate.

Experimental evidence indicated that rainbow trout euglobulins were precipitated at *p*H 5.8 with low ionic strength (0.001%) tris (hydroxmethyl) amino methane–acetate buffer leaving pseudoglobulins in solution.

Euglobulins and pseudoglobulins of immunized rainbow trout serum were separated and an agglutination test carried out to determine presence of agglutinating antibodies.

RESULTS

Electrophoresis of rainbow trout serum on paper, cellulose acetate, and starch gel produced patterns indicating the presence of three major protein components. Paper electrophoresis appeared to be satisfactory for evidence of complete salt separation and, therefore, was used rather than the other matrices. Figure 1 shows the paper electrophoretic pattern of the 1000-fish serum composite sample compared with a normal human serum electrophoretic pattern. Note the nearly complete lack of a component in rainbow trout which has similar mobility to the γ-globulin component of human serum. The most mobile component of rainbow trout did not correspond exactly to that of the albumin component of human serum. These electrophoretic analyses were made in the same chamber at the same time.

Separation of the components of rainbow trout serum with sodium sulfate is demonstrated in Fig. 2. A graphic pattern from paper electrophoretograms indicates the three major protein components. Paper electrophoresis also demonstrates the separation of major components by 17 and 22% sodium sulfate. The third major component remained in the supernatant from 22% sodium sulfate precipitation.

Serially fractionated proteins of rainbow trout serum are given in Table I. These data indicate that all *A. hydrophila* antibody is present in proteins precipitated at 16, 18, and 20% sodium sulfate. There does not appear to be a significant difference in quantitative protein between immune serum and serum from nonimmune fish.

TABLE I. Protein fractionation and anti-*A. hydrophila* titer in serum of immunized and non-immunized rainbow trout.

	Nonimmunized fish sera			Immunized fish sera		
Per cent Na_2SO_4	Mg protein/ml	% of total protein	Titer	Mg protein/ml	% of total protein	Titer
12	4.4	9.6	–	3.9	8.0	–
14	5.0	10.9	–	5.8	11.8	–
16	6.0	13.1	–	6.8	13.9	1:16
18	6.2	13.5	–	5.2	10.6	1:16
20	3.4	7.4	–	4.6	9.4	1:16
22	4.6	10.3	–	6.4	13.1	–
24	6.6	14.4	–	4.8	9.8	–
26	6.4	14.0	–	5.3	10.8	–
Supernate	3.1	6.8	–	6.2	12.6	–
Total:	45.7			49.0		
Whole serum	42.7		–	46.8		1:16

Figure 1 shows the electrophoretic appearance of all fractions precipitated at 20% sodium sulfate and the supernatant from that precipitation. Table II shows the antibody assay of serum of rainbow trout which had received parenteral injections of *A. hydrophila*. Note that all antibody was apparently not present within one major serum protein component (Fig. 1, Table II). However, the antibody was present within the electrophoretically least-mobile proteins.

TABLE II. *Aeromonas hydrophila* antibody titer in the 20% w/v sodium sulfate precipitate and supernatant of immunized rainbow trout.

Route of immunization	Method of suspension	Whole serum	Precipitates 20% w/v Na_2SO_4	Supernatant from 20% w/v Na_2SO_4
Intramuscular	Adjuvant	1:16	1:64	–
Intramuscular	Saline	1:16	1:64	–
Intraperitoneal	Saline	1:16	1:32	–
Nonimmunized	None	–	–	–

The results obtained from sera of parenterally immunized fish through a 180-day immunization period are given in Table III. These results indicate that

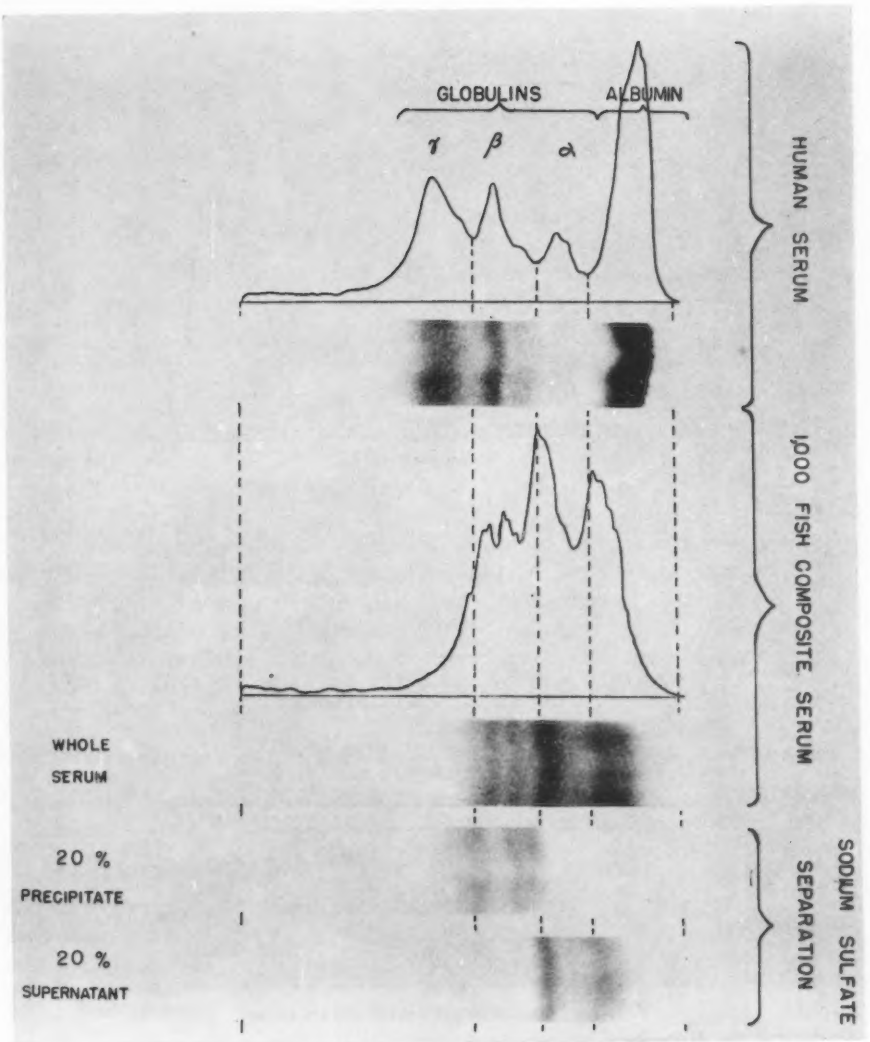

FIG. 1. Rainbow trout compared with human serum.

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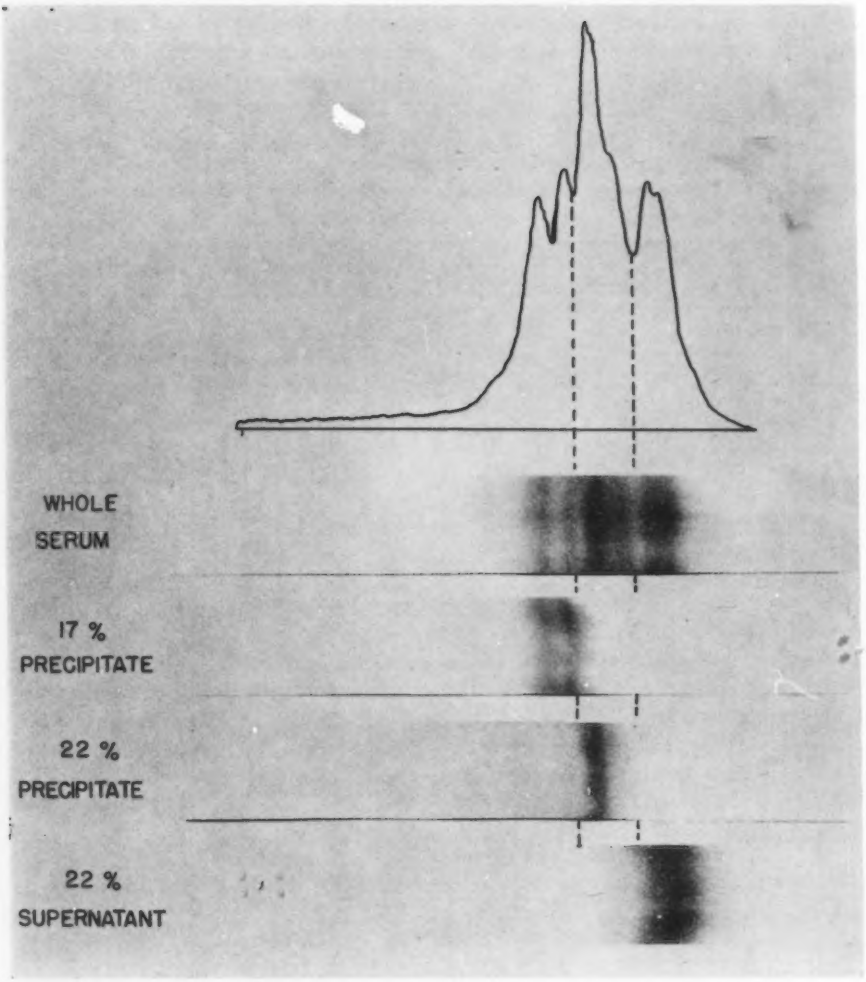

FIG. 2. Serum separation with sodium sulfate.

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TABLE III. *Aeromonas hydrophila* antibody in major serum components of immunized rainbow trout.

Days of immunization	Whole serum:titer	Fraction I 17% w/v Na_2SO_4[a]	Fraction II 22% w/v Na_2SO_4[a]	Fraction III supernate
0	–	–	–	–
32	–	±	±	–
60	±	1:32	1:16	–
75	1:2	1:32	1:16	–
90	1:4	1:64	1:8	–
124	1:4	1:64	1:16	–
163	1:8	1:64	1:32	–
180	1:16	1:128	1:16	–

[a]The protein from 6 ml of serum of immunized fish was separated and each precipitate made up to 1.5 ml with 0.1 ionic strength *p*H 7.8 disodium–monosodium phosphate buffer.

relatively more antibody protein of rainbow trout was precipitated by 17% sodium sulfate than by 22%. All antibody protein was precipitated by 22%; sodium sulfate; no antibody was present in the supernatant from 22% sodium sulfate.

The antibody proteins of rainbow trout immunized against *A. hydrophila* were found to be eugloblin in nature. When the protein precipited at 20% sodium sulfate was subjected to 0.001 M tris (hydroxmethyl) amino methane–acetate at *p*H 5.8, all antibody protein precipitated leaving none in the supernatant. Antibody titers of nonimmune serum were negative and remained negative throughout the manipulation (Table IV).

TABLE IV. *Aeromonas hydrophila* antibody titer and total protein in separated rainbow trout serum.

Serum or component designation	Titer	Total protein (*mg/ml*)	% total protein
Immune serum (whole):	1:16	58.0	100.0
a) Precipitate at 20% Na_2SO_4	1:16	28.6	49.3
Euglobulins	1:16	18.0	31.0
Pseudoglobulins	–	10.9	18.8
b) Supernatant at 20% Na_2SO_4	–	29.4	50.7
Nonimmune serum (whole):	–	53.9	100.0
a) Precipitate at 20% Na_2SO_4	–	28.4	54.5
Euglobulins	–	17.9	33.4
Pseudoglobulins	–	11.5	21.3
b) Supernatant at 20% Na_2SO_4	–	25.5	45.5

DISCUSSION

The major groups of serum protein of rainbow trout vary greatly from those of higher animals. There is no particular electrophoretic correlation as to type of globulin component with those of human serum, except possibly β-globulin. Salt solubility of the component of rainbow trout serum, which had the electrophoretic mobility of human β-globulin, differed from that of human β-globulin. Human β-globulin was completely removed at 19% sodium sulfate (Kibrick and Blonstein, 1948). The electrophoretically similar component in rainbow trout precipitated completely at 17% sodium sulfate. A component with the electrophoretic mobility and salt solubility of the γ-globulin of human serum was completely lacking (Fig. 1). Human γ-globulin was precipitated quite well at 15% sodium sulfate (Kibrick and Blonstein, 1948). Approximately 20% of the protein in rainbow trout serum was precipitated at sodium sulfate concentrations up to 15%; however, these proteins acted differently than γ-globulin on electrophoresis (Table I; Fig. 1). The albumin component of human serum remained in the supernatant following treatment at 26% sodium sulfate whereas the α-globulin was precipitated (Kibrick and Blonstein, 1948). The electrophoretically most rapidly moving component of rainbow trout serum precipitated at 26% sodium sulfate. This component appeared to be soluble in 22% sodium sulfate (Fig. 2).

These results indicate that a different group of proteins are formed with antibody activity in rainbow trout than in higher animals. Salt solubility and electrophoretic mobility are an indication of molecular size. The results of these manipulations on rainbow trout blood serum indicate these fish do not have serum protein molecules as large as the γ-globulin molecules of higher animals. Therefore, molecules smaller than human γ-globulin must be formed as antibody molecules.

Humoral antibodies in rainbow trout immunized against *A. hydrophila* could be precipitated by 20% sodium sulfate. This protein fraction was found to contain two major protein groups when subjected to electrophoresis (Fig. 1). These results would indicate presence of active antibody protein within the two major groups of protein. However, trailing of one group of protein may have contaminated the second group with measurable antibodies although results given in Table I will not bear this out. Precipitation at 20% sodium sulfate concentration did separate all of the slowest moving component as well as the least mobile portion of the intermediate component (Fig. 1; Tables I and II).

Rainbow trout serum proteins could be assigned to euglobulins and pseudoglobulins. All proteins with antibody activity could be classified as euglobulins. Initial separation of immune serum at 20% sodium sulfate removed approximately half of the extraneous proteins. Solution of the precipitate and subsequent precipitation at *p*H 5.8 with 0.001 M tris (hydroxymethyl) amino methane–acetate buffer yielded a product which was approximately 30% of the original serum protein. Apparently the same amount of antibody protein remained in the product because the titer remained the same (Table IV).

The results just discussed show that the serum proteins of rainbow trout which contain antibodies are euglobulins. Further, these proteins are precipitated at 20% sodium sulfate. They also have the electrophoretic mobility of β-globulins and possible slow α-globulins of higher animals.

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NOTES

Records of *Cryptobia salmositica* from Sockeye Salmon from the Fraser River Drainage and from the State of Washington[1,2]

Although Becker and Katz (1965) have reported *Cryptobia salmositica* infections in four of the five species of Pacific salmon endemic to North America, they were unable to find this flagellate in the sockeye, *Oncorhynchus nerka* (Walbaum). This note records *C. salmositica* for the first time in sockeye. In addition, the first record for *Cryptobia* in the Fraser River system is reported.

A 4-year-old male sockeye was captured by P. T. K. Woo and J. R. Adams at the counting fence in the inlet of Cultus Lake, British Columbia. Observation of air-dried and Giemsa-stained blood smears collected from this fish on November 10, 1964, revealed at least 26 specimens of the hemoflagellate.

Three of five post-spawning moribund sockeye collected in the Cedar River, near the town of Maple Valley, Washington, on November 13, 1965, were positive for *Cryptobia*. The air-dried smears were stained with Giemsa and were observed with an oil immersion objective and the relative intensity of parasitemia was determined by the criteria given by Becker and Katz (1966).

The detailed record of the observations is given in the following table:

Fish	Sex	Length[a] (*cm*)	Infection intensity
1	Female	46.8	3+
2	Male	48.4	2+
3	Female	42.6	4+
4	Male	43.6	Negative
5	Female	44.7	Negative

[a]Length measurements are from mideye to posterior edge of the hypural plate.

This parasite has now been recorded from all species of *Oncorhynchus* indigenous to North America. It was first observed in coho salmon, *O. kisutch*, from Soos Creek, a tributary of the Green River, King County, Washington (Katz, 1951), and subsequently from numerous locales in Oregon (Davison et al., 1954; Becker and Katz, 1965), British Columbia, and Washington (Becker

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and Katz, 1965). In chinook salmon, *O. tshawytscha*, *Cryptobia* was first observed in fingerlings in a California hatchery (Wales and Wolf, 1955), and subsequently in fingerlings and an adult from the State of Washington (Becker and Katz, 1965). It was recorded from pink salmon, *O. gorbuscha*, from several Western Washington streams and from a chum salmon, *O. keta*, taken from the Nooksack River, Whatcom County, Washington (Becker and Katz, 1965).

This flagellate is not restricted to *Oncorhynchus* in rivers of North America, for a *Cryptobia* was reported in the blood of adult pink salmon and chum salmon found in the My River, a tributary of the Amur River, USSR (Makeyeva, 1956; Pavlovskii, 1962).

Cryptobia has been reported from salmonids other than those belonging to the genus *Oncorhynchus*: in rainbow (*Salmo gairdneri*) and brown trout (*S. trutta*) by Wales and Wolf (1955), and in steelhead and mountain whitefish, *Prosopium williamsoni*, from Soos Creek by Becker and Katz (1965). This flagellate has been observed in at least seven species of cottids, in catostomids, cyprinids, and the threespine stickleback (*Gasterosteus aculeatus*) from Washington, Oregon, and California (Wales and Wolf, 1955; Becker and Katz, 1965). These records indicate that *Cryptobia salmositica* is widely distributed in many species of freshwater fish indigenous to the western coast of North America.

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Northern Range Extension Record for the Pygmy Rockfish (*Sebastodes wilsoni*)

During a recent examination of the rockfish (Scorpaenidae) collection at the Institute of Fisheries, University of British Columbia, three specimens of the pygmy rockfish, *Sebastodes wilsoni* (Gilbert, 1915), not previously recorded from the area of capture were noted (Cat. No. BC64-139). The fish, 59–137 mm fork length (two males and one undetermined sex), were collected by Mr R. Kearns in northern Hecate Strait (53°40′N lat, 131°30′W long) on August 15, 1963.

Prior to the capture of these specimens, the northern range limit of *S. wilsoni* had been reported as Swiftsure Shoals, British Columbia (Clemens and Wilby, 1961). Phillips (1957) lists the northern range limit as Vancouver, British Columbia. The known range of this species is thus documented to extend northward approximately 400 miles from Swiftsure Shoals.

Morphometric ratios and meristic counts of the Hecate Strait specimens of *S. wilsoni* agree closely with those in California (Phillips, 1957). There are a few minor exceptions in the ratios. The frequency of snout length into head length is greater in the Hecate Strait specimens (4.3–4.4 as compared with 4.0–4.2 in California); frequency of the second anal fin spine into head length is also greater (1.9–2.1 as compared with 1.8); and frequency of the ventral length of caudal peduncle into head length is less (1.4–1.5 as compared with 1.6–1.7). The only variation in the meristic counts occurred in the number of anal fin rays. Two of the specimens have six anal rays as reported by Phillips (1957), but the third specimen has five rays. In view of the small number of specimens examined and the wide geographical separation, these differences are not considered significant.

S. wilsoni closely resembles *S. emphaeus* (Starks, 1911) in size (maximum, 15–19 cm) and possesses the same head spines (nasal, preocular, postocular, tympanic, and parietal) and second anal fin spine longer than the third. The two species differ in color and certain morphometric ratios and meristic counts. Hitz (1965) notes that fresh specimens of *S. emphaeus* lack the brownish-red or orange stripe along the lateral line that is found in *S. wilsoni*. Phillips (1957) reports the ratio of orbit width into head length as 3.0–3.1 for *S. wilsoni*, and Starks (1911) reports 3.2–3.5 for *S. emphaeus*. The two species differ in number of dorsal fin rays (13–14 for *S. wilsoni* and 15 for *S. emphaeus*) and anal fin rays (5–6 for *S. wilsoni* and 7 for *S. emphaeus*).

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A Second Record of an Accessory Fin on *Esox lucius*

An accessory fin attached to the ventral surface of the head of a pike, *Esox lucius*, was described by Lawler (1964). Since this anomaly was found in 1963, approximately 3000 more pike were examined before another accessory fin was observed, this time on the ventral surface of the body between the pectoral and pelvic fins.

The fish (Fig. 1A), 35.5 cm fork length, had an accessory fin projecting from the ventral surface — by measurement, closer to the pectoral fin than to the pelvic fin in position, but in appearance more closely resembling a pelvic fin than a pectoral fin.

Comparative lengths of the fins are: pectoral fin, 4.5 cm; pelvic fin, 4.4 cm; accessory fin, 3 cm. The fin ray counts were: pectoral 15, pelvic 11, accessory 14. Although this fin resembled a pelvic fin in appearance, because of the ray count it probably could be best described as a supernumerary pectoral fin.

The method of attachment was of interest, as the fin appears to have some articulation, but an X-ray photograph (Fig. 1B) did not reveal any bony attachment in the body of the fish. The accessory fin and the flesh to which it was attached was excised and then cleared and stained. There appeared to be some evidence of an attachment to the body and dissection of the cleared flesh revealed a bony cartilaginous structure that had not been visible in the X-ray plates. This structure, if not damaged in dissection, was roughly rectangular in shape, thickened on the side distal to the point of the fin, but did not resemble either the typical pectoral or pelvic girdles with their associated bones and processes.

This accessory fin possibly arose from an unusual development of the muscle buds during the early embryonic period, but as this appears to be one of the paired fins, it might have been expected that a similar fin would have appeared on the other side of the animal.

The writer gratefully acknowledges the cooperation of Dr W. B. Scott, of the Department of Ichthyology and Herpetology, the Royal Ontario Museum, Toronto, Ontario, for preparing the X-rays and for clearing and staining the specimen, and Mr S. T. Zettler, of this Station, for the photographs.

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(FIG. 1 *follows*)

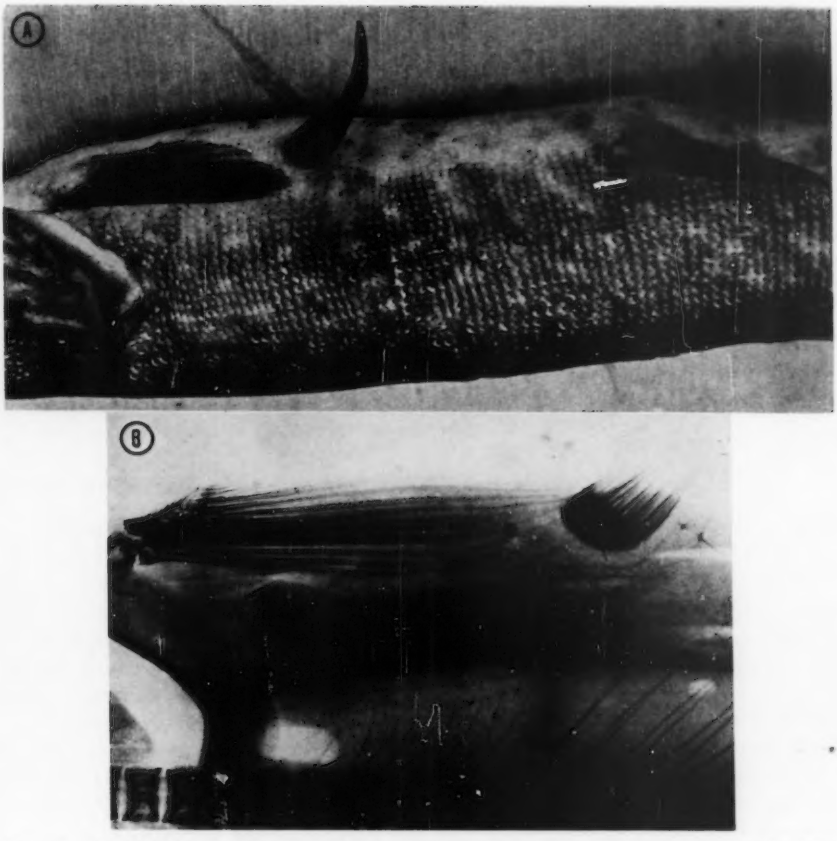

FIG. 1. A, right side of pike, *Esox lucius*, showing accessory fin; B. X-ray photograph of fin.

Food and Feeding Apparatus of Two Pelagic Shrimps

This report describes the feeding apparatus and stomach contents of two shrimp species found off the Oregon coast. The shrimps, a carid, *Pasiphaea pacifica* Rathbun, and a penaeid, *Sergestes similis* Hansen, are abundant in epipelagic waters at night (Pearcy and Forss, 1966) and are thought to be important intermediate organisms in the oceanic food web. Despite this, little is known about the food habits or trophic ecology of these species in the marine ecosystem.

The specimens examined were captured with a 2-m (6-ft) Isaacs–Kidd midwater trawl in depths from 200 m to the surface, 28–83 km from shore (Pearcy, 1964). All samples were collected at night. Trawl towing times averaged less than 1 hr each. Preserved specimens from several seasons were selected to avoid bias caused by seasonal changes in food habits. After measurement of carapace length (distance from orbital notch to the median posterior edge of the cephalothorax), an incision was made in the carapace of each shrimp, and its pharynx, stomach, and the anterior portion of its intestine were extracted with small forceps. Next, the digestive tract was opened and its contents examined under a dissecting microscope. Finally, the mouth parts were drawn to scale with the aid of an ocular micrometer.

Pasiphaea pacifica

Most specimens (about 80%) had empty stomachs. The stomach contents of 25 *P. pacifica* which contained food (Table I) indicated that crustaceans chopped into many pieces comprised the bulk of the diet. The size and general appearance, particularly the eye shape, of the crustaceans found in the stomachs indicated that most were *Euphausia pacifica*, a species which is abundant off Oregon. Although only one copepod was definitely recognized, some of the items listed as crustacean fragments may have been copepod remains.

The frequent occurrence of arrow-worm (Chaetognatha) grasping spines in full as well as in otherwise empty stomachs (Table I) poses a problem in interpretation. On one hand, the presence of these 1–2-mm long spines may indicate only that arrow-worms are occasionally eaten, with a few indigestible spines remaining for days or even weeks as evidence of the meal. On the other hand, some shrimp stomachs yielded 26–60 spines, proving that three or more arrow-worms (each with a maximum of about 12 spines) had been consumed.

The mouth parts of *P. pacifica* (Fig. 1) appear to be better adapted for manipulating relatively large prey than for capturing minute organisms. The maxillae and maxillipeds are comparatively short, stout, and lack setae necessary to form an effective filter. There are no mandibular palps, and absence of grinding surfaces on the median faces of the mandibles indicates that this species probably could not crush pteropod shells or other shelled organisms. Each

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TABLE I. Stomach contents of *Pasiphaea pacifica*.

Date of capture	Carapace length (*mm*)	Contents	Number of arrow-worm spines
December 1962	21	One copepod	60
February 1963	22	One small crustacean	0
February 1963	20	Fragments of small crustacean	7
February 1963	20	Fragments of small crustacean	0
April 1963	18	One small crustacean	0
April 1963	20	Fragments of small crustacean	0
May 1963	12	Appendages of small crustacean	0
May 1963	20	One small crustacean	0
May 1963	25	One small crustacean	6
May 1963	22	One small crustacean	2
May 1963	24	One small crustacean	1
May 1963	15	Fragments of small crustacean	0
May 1963	11	One euphausiid	0
May 1963	22	One euphausiid	5
May 1963	13	One euphausiid	0
May 1963	20	One euphausiid	47
July 1963	21	One small crustacean	0
July 1963	22	One euphausiid	0
July 1963	19	One euphausiid	0
July 1963	18	One euphausiid	0
July 1963	15	One or two small crustaceans	0
February 1964	18	One euphausiid	4
February 1964	15	One euphausiid	26
February 1964	17	One euphausiid	18
February 1964	11	Fragments of small crustacean	0

mandible possesses a long cutting edge with sharp teeth, accounting for the well-chopped condition of food items in the stomach.

The stomach is a long, thin-walled sac with few exterior muscle attachments. At its posterior end a small gastric mill with toothed medial surfaces probably grinds food passing into the intestine. When empty, the stomach is so transparent that it is possible to see through the carapace and stomach walls to the floor of the body cavity.

Sergestes similis

Again, approximately 80% of the stomachs examined were empty. Small crustaceans, calanoid copepods, and euphausiids form the diet of *S. similis* (Table II). Food items in this penaeid had been swallowed in larger pieces than those found in *P. pacifica*. Copepods were swallowed whole. Apparently small oil globules from the copepod bodies were released and remained in the stomach after the flesh and exoskeleton had been digested and passed into the intestine. No evidence of arrow-worms was found.

Mouth parts of *S. similis* are longer and more setose than those of *P. pacifica* (Fig. 1). The mandibles have sharp, toothless cutting edges, small molar processes, and long palps. In addition to these feeding appendages, the last two pairs of thoracic legs possess long setae which in turn bear closely spaced

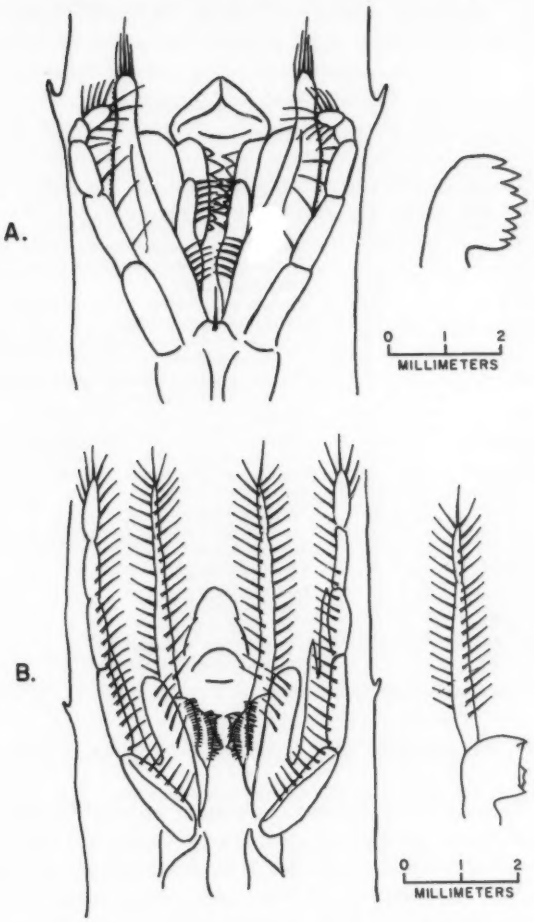

FIG. 1. Mouth parts and right mandible of A., *Pasiphaea pacifica* (carapace length 11 mm), and B., *Sergestes similis* (carapace length 18 mm). Ventral views.

setules (tiny hair-like bristles) forming a fine-meshed structure possibly used to capture or hold prey. With these feeding devices *S. similis* can utilize food in a wide range of sizes. Indeed, laboratory experiments show that it can capture and consume living *E. pacifica* half its own length as well as *Artemia salina* nauplii less than 1 mm long.

A short esophagus leads from the mouth to a small, heavily sclerotized stomach. The stomach is very muscular and is attached to the surrounding body walls by numerous muscle bands. It is equipped posteriorly with an

TABLE II. Stomach contents of *Sergestes similis*.

Date of capture	Carapace length (*mm*)	Contents
December 1963	9	One small crustacean
December 1963	10	Fragments of small crustacean
December 1963	13	One euphausiid
December 1963	8	Fragments of small crustacean
April 1964	12	Fragments of small crustacean(s)
April 1964	11	Fragments of small crustacean(s)
April 1964	11	One euphausiid
April 1964	10	Fragments of small crustacean(s)
July 1964	13	Six calanoid copepods
July 1964	7	Two calanoid copepods plus fragments of one small crustacean
July 1964	8	Three calanoid copepods plus one 0.25-mm diameter egg
July 1964	9	Several oil globules (copepods)
July 1964	12	Several oil globules (copepods)
July 1964	8	Several oil globules (copepods)
July 1964	8	Several oil globules (copepods)
October 1964	12	Two euphausiids
October 1964	10	One euphausiid
October 1964	10	Unidentifiable animal fragments
October 1964	9	Fragments of crustacean(s)
October 1964	8	One euphausiid
January 1965	11	One euphausiid
January 1965	11	Two euphausiids
January 1965	15	Two euphausiids
January 1965	15	Three calanoid copepods
January 1965	11	One calanoid copepod

efficient gastric mill ensuring that large food items swallowed are properly reduced.

Both the shrimps are carnivores. Despite a careful search, no diatom frustules or other traces of plant material were found in their stomachs. The contribution of arrow-worms to the diet of *P. pacifica* may be relatively small, although this point is not resolved. These observations agree closely with those of Osterberg et al. (1964), who placed both these shrimps in trophic level III (carnivores which prey on herbivores). Tchindonova (1959) examined a few stomachs of *S. similis* collected in the northwestern Pacific and found primarily copepods.

It is instructive to contrast the function and anatomy of the mouth parts and stomachs of these shrimps. The thin-walled, non-muscular stomach and small gastric mill of *P. pacifica* are poorly adapted for reducing large pieces of food, but its mandibles bear sharp teeth which incise the prey into manageable pieces before ingestion. *Sergestes similis*, on the other hand, has a strongly sclerotized, well-muscled stomach and a gastric mill capable of breaking down larger food items, but its mandibles are correspondingly smaller and presumably less efficient than those of *P. pacifica*. Tchindonova (1959) also noted this correlation between feeding appendages and size of food items in the stomachs

of various Decapods. She stated that *S. similis*, *S. japonicus*, and *Hymenodora glacialis* eat small prey whole, whereas small specimens of *H. glacialis*, *H. frontalis*, and *Gennadas borealis* grind their food.

In summary, both *P. pacifica* and *S. similis* feed primarily on euphausiids, but mechanically degrade them in different ways. *Pasiphaea pacifica* apparently supplements its diet with carnivorous arrow-worms and *S. similis* with copepods. *Euphausia pacifica* has been shown to consume animals as well as plants (Ponomareva, 1954). Consequently, both shrimps might best be placed partly in trophic level III and partly in trophic level IV (carnivores which eat trophic level III carnivores).

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Some Factors Influencing the Distributions of Brook Trout and Young Atlantic Salmon

Juvenile Atlantic salmon (*Salmo salar* L.) and brook trout (*Salvelinus fontinalis* (Mitchill)) frequently cohabit the same stream. As a result, in the summers of 1963 and 1964, comparisons of habitat preference were made on the two species. Skin-diving techniques were used (Keenleyside, 1962; Gibson, MS, 1965). Juvenile salmon, or 'parr', are found predominantly in riffles and trout in pools. Quantitative observations were made on these distributions and on diurnal changes in cover preference.

Observation stations were chosen in the Northwest Miramichi river and some of its tributaries, in northcentral New Brunswick. A study area for repeated observations was chosen in Little River, a tributary. This study area was 6 m across at the upstream end, widening to 8 m across at its downstream end. Shallow rapids in the upstream section were divided into an 'upper riffle' and 'lower riffle' 9 m and 8 m long respectively. A pool formed the downstream end, $6\frac{1}{2}$ m long on the left bank, and $12\frac{1}{2}$ m long on the right bank (looking downstream). Depths at low water level varied from about 15 cm at the upstream end to 1 m at the lower end. All sections of the study area had open parts, and parts with cover providing shade, and for a month an artificial cover, 1.8 m^2, was placed in a previously unshaded section.

Salmon parr were more numerous in rapid water than in the pool, whereas trout were more numerous in the pool section. This included both day and evening observations (Table I); but at night both species were seen resting on the bottom in quiet water. At low water levels the mean number of trout differed from that of salmon in the pool and in the upper riffle ($P < 0.01$)

TABLE I. Relation between fish locations and water velocity. Mean numbers (standard deviations in brackets) of salmon and trout seen during daylight in pool, lower riffle, and upper riffle of the study area in 27 observation periods between July 20 and September 13, 1964. Low water level established arbitrarily from lowest recorded to 4.5 cm above this; medium level from 5–9 cm above lowest recorded.

	Low water level (18 observations)			Medium water level (9 observations)		
	Pool	Lower riffle	Upper riffle	Pool	Lower riffle	Upper riffle
Water velocity (*cm/sec*)	30.5 (0.08)	52 (0.16)	89 (0.15)	50 (0.12)	85 (0.18)	115 (0.20)
Trout	10.8 (5.5)	2.4 (2.0)	0.8 (0.7)	10.2 (2.3)	5.6 (1.7)	0.4 (0.5)
Salmon	2.8 (1.5)	2.3 (1.2)	3.7 (1.7)	4.3 (1.6)	3.1 (1.0)	4.7 (0.9)

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but not in the lower riffle ($P > 0.05$). At medium water level there were more salmon than trout in the upper riffle ($P < 0.01$), but no significant difference between the means ($P > 0.05$) was found in the other sections. Using the '*t*' test, the mean number of salmon in the pool at medium water levels was greater than at low water levels ($P < 0.01$). The mean number of trout in the lower riffle was also significantly greater during medium water levels than during low water levels ($P < 0.05$). No significant change in the population of salmon or trout was found in the upper riffle ($P > 0.05$). Presumably the changes were caused by fish moving into the area from adjacent water with higher water velocities. At medium and high water levels there was a strong current through tree debris at the end of the pool, and trout were not found there, although usually they were seen there at low water levels. Although more trout were seen in quiet backwaters and under the right bank, the total number in the pool did not increase at higher water levels.

Trout are known to move into cooler water when water temperature rises above about 20 C (Fry, 1951; Elson, 1942), but the movement of salmon parr into cooler water is not as well documented. Huntsman (1942) observed salmon parr in cooler water when the river temperature was 30 C. I made observations on salmon parr moving into spring seepage of 17 C when the river temperature rose above about 22 C. They were grouped in the cool water, oriented towards the source of spring seepage, showing no territorial behaviour (Fig. 1). Salmon parr were found feeding in the main river, but not trout, although the latter were seen there when the water was cooler. Evidently local springs attract salmon as well as trout, but are not necessary for the survival of salmon, which can utilise the river at higher temperatures than trout.

Trout in general remained under overhanging cover, such as alder bushes, or submerged logs or branches except at times of low illumination in the early morning and in the evening. Salmon parr were usually seen away from such cover, feeding in brightly lit open areas of the stream all day, although they hid under stones when alarmed. Diurnal changes in cover preference are shown in Table II. Distributions in the day and evening differed for trout ($P < 0.01$) but not for salmon ($P > 0.05$). No significant difference was found between distributions on cloudy and on sunny days for either trout

TABLE II. Mean numbers of fish observed in open, and of all fish seen, in the study area between July 20th to September 13th, 1964. Low water level observations only, to minimize changes in local population caused by changes in water level. Standard deviations in brackets. Time is Atlantic standard.

	Day (9 AM – 4 PM) (11 observations)		Evening (4:30 PM– 7:30 PM) (6 observations)	
	Trout	Salmon	Trout	Salmon
In open	4.4 (2.8)	8.2 (3.3)	14.6 (6.1)	10.0 (1.9)
Total no. of fish seen	11.6 (3.6)	8.8 (3.4)	17.0 (4.8)	10.3 (1.9)

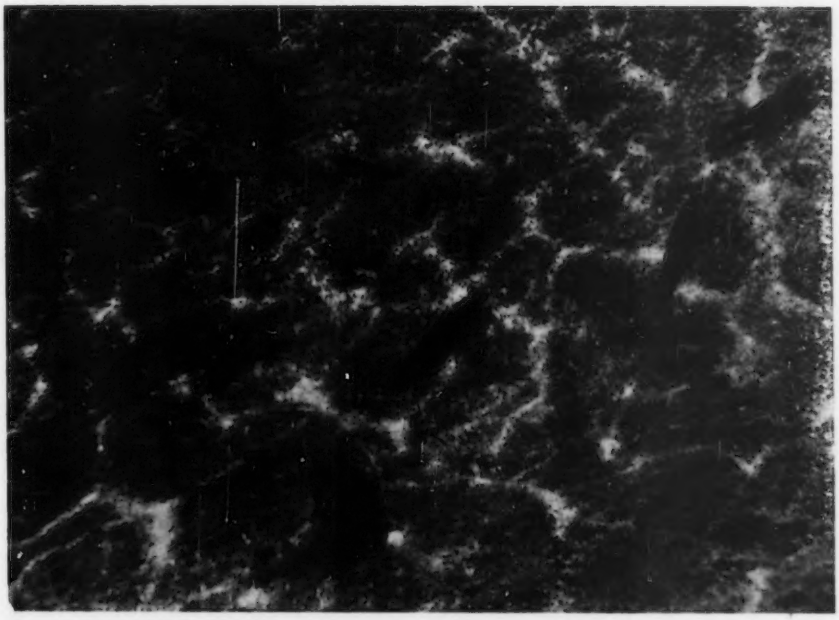

FIG. 1. Seven salmon parr in spring seepage, out of a group of 20 in this location. July 29, 1964.

FIG. 2. School of sea trout, average length about 40 cm, migrating upriver. June 9, 1964.
Gibson — J. Fish. Res. Bd. Canada

FIG. 3. Five trout and three salmon parr in a bright area, with negligible waterflow, oriented towards cool spring seepage. July 29, 1964.

FIG. 4. School of small trout (12–14 cm) holding position in an area of open pool. September 10, 1964.

or salmon. An artificial cover attracted trout in its shade, where previously trout were not seen. In 11 daytime observations, 9 trout were seen under the cover, and 16 in the same section (lower riffle), away from the cover. Twenty-nine salmon were seen in the lower riffle away from the cover, but none under the cover. Gibson and Keenleyside (1966) duplicated these reactions of trout and salmon to cover in aquarium experiments. At observation stations where many trout were found in open sunlight (Figs. 2, 3, 4), there was no available cover.

The crepuscular activity of trout allows them to take advantage of the greater amount of food available in the evening (e.g., Sprules, 1947; Waters, 1962; Elliot, 1965), and during the day overhanging cover shields them from surface predators. Salmon parr, being usually in faster water than trout, are fairly well hidden by surface turbulence; also, apparently a rough substrate, as is found in riffle areas, provides protection for salmon parr (Gibson and Keenleyside, 1966).

Winter observations were not made, but Allen (1940, 1941) found salmon parr, and Cooper (1953) found trout, to be in pools at this time.

Feeding habits of the two species are similar (Keenleyside, 1962), and food preferences appear to be unimportant in separating them. Judging by work on other salmonids living in close association (e.g., Nilsson, 1965; Hartman, 1965), inter-specific competition is probable, but, as described above, could be minimized by habitat segregation of the two species in space and time.

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Colour Variant of Bocaccio (*Sebastodes paucispinis*) in British Columbia Waters

On June 20, 1965, a bocaccio, or salmon rockfish (*Sebastodes paucispinis*), of a gold-orange colour was caught by Captain Don Baker of the dragger *Jo Marc*. It was taken on the Horseshoe ground in Hecate Strait, British Columbia (approx 52°57′N lat, 130°138′W long). The specimen was given to our Vancouver port sampler Mr R. M. Wilson, who in turn sent it to Nanaimo Biological Station for identification.

The specimen was a male with a fork length of 638 mm; the gonads were dormant. Bocaccio's normal colour is a light olive-brown becoming pink on sides and belly. The species is easily recognizable and common in British Columbia waters.

This golden colouration, a condition in which only the orange and red pigments develop, has been referred to by Norman (1934) as "xanthochroism." He observed this abnormality in a dab (*Limanda*) from the North Sea. It has also been reported in a Dover sole (*Microstomus pacificus*) from northern California (McCormick and Baldwin, 1952), and in a blackcod (*Anoplopoma fimbria*) from Monterey Bay, California (Phillips, 1952).

The author expresses his thanks to Captain Baker and Mr Wilson for the opportunity to examine this specimen.

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*Articles indicated by an asterisk are included as "titles only," and will not be reproduced in the Studies binding.

Copies of individual reprints, if available, may be obtained from the authors or Board establishments through which the investigations were conducted.

Reprints of these articles are included in an annual volume of "Studies", composed of two parts. These are distributed to a selected mailing list. (Articles numbered 985 to 1019 appeared in the Studies for 1966, Part 1.)

INDEX TO PUBLICATIONS FOR 1966[1]

In 1957 the Fisheries Research Board of Canada published Bulletin No. 110 containing a list of the articles in most of its series of publications and Studies that had appeared up to the end of 1954, together with a subject–author index to many of those series. That Bulletin is now out of print. A successor to it that will list and index *all* Board publications and Studies up to the end of 1964, plus many items that did not get included in the Studies, is completed and is expected in 1967.

From 1955 to 1964 inclusive, a subject–author index to all articles in the Journal only has been included in the last issue (No. 6) of each Journal volume. Commencing with the 1965 volume of the Journal the annual index was expanded to cover not only articles in the issues of that volume, but also such Fisheries Research Board of Canada Bulletins, Circulars, and Studies issued during the year in time to be included in the index.

During 1966 the Journal has been issued monthly instead of bi-monthly. The present subject–author index is based on: (*a*) the 12 issues of Volume 23 of the Journal; (*b*) Bulletins No. 150–154 issued during 1966, plus general references to Bulletin No. 155 ("Fishes of the Atlantic Coast of Canada" which contains its own index and which was largely incorporated in the forthcoming index Bulletin mentioned in the above first paragraph); No. 122 which was reprinted without revision, and No. 140 which was published in French. These titles are listed in the Lists of Publications for 1966. (*c*) Circular series from the Board's establishments issued during 1966 in time to be included; (*d*) Studies No. 971–1109 (reprints of articles published in other periodicals, bound annually in two parts); (*e*) general references to the 1964 Annual Report, and to the 1964 Review of the Fisheries Research Board of Canada; "Miscellaneous Special Publications" includes special bindings, and pamphlets, which do not belong to a particular series of FRB publications. Lists of titles of the individual publications and articles immediately follow this index, arranged under the following types of publications. (The list of articles in this Volume 23 of the Journal is in the form of a table of contents of its 12 issues, suitable for binding with the volume).

Abbreviations used in the index for types of publications:

J — Journal of the Fisheries Research Board of Canada
B — Bulletin of the Fisheries Research Board of Canada
AR — 1964 Annual Report of the Fisheries Research Board of Canada
R — 1964 Annual Report of the Fisheries Research Board of Canada
MSP — Miscellaneous Special Publications.

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[1]Subject index prepared by Neal M. Carter.

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Circulars of the Fisheries Research Board of Canada:

CCG — Biological Station, London, Ont. (*now located at Winnipeg, Man.*)
CHN — Halifax Laboratory, Halifax, N.S.
CJG — Biological Station, St. John's, Nfld.
CNG — Biological Station, Nanaimo, B.C. (General series)
CNS — Biological Station, Nanaimo, B.C. (Statistical series)
CSG — Biological Station, St. Andrews, N.B. (General series)
CVG — Vancouver Laboratory, Vancouver, B.C.

Articles by FRB Staff published in non-Board publications:

S — Studies of the Fisheries Research Board of Canada

Other abbreviations:

The Provinces and Territories of Canada are abbreviated to:

Alta. (Alberta)	N.W.T. (Northwest Territories)
B.C. (British Columbia)	Ont. (Ontario)
Man. (Manitoba)	P.E.I. (Prince Edward Island)
N.B. (New Brunswick)	Que. (Quebec)
Nfld. (Newfoundland)	Sask. (Saskatchewan)
N.S. (Nova Scotia)	Yuk. (Yukon)

Certain geographical areas (particularly oceans) have their major subdivision designated by N (north), S (south), E (east), W (west), NE (northeast), etc., also Atl. (Atlantic), Pac. (Pacific).

Certain international commissions are commonly referred to as:
ICNAF (International Commission for the Northwest Atlantic Fisheries)
INPFC (International North Pacific Fisheries Commission)

In the index references, "re" is frequently used to imply "in relation to," "in connection with," and similar meanings; "vs." to imply such meaning as "in contrast to," "as opposed to."

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(3): 341 (for fish swimming endurance)
(4): 611 (side-trawl for research vessel)
(6): 813 (testing toxicity of pulpmill effluent to fish)
(6): 929 (micro starch-gel electrophoresis)
(7): 983 (for illumination effect on rainbow trout)
(7): 1025 (for gradient elution chromatography)
(7): 1089 (portable press for salmon scale impressions)
(8): 1271 (aquarium for photography at sea)
(9): 1411 (electrical analog model for wind-driven currents)
(9): 1477 (small holding tank for fish)
(11): 1805 (speed calibration curves for histogram sea current meter)
B 151 (for freshwater fishes specialty products production)
CCG 7: 16 (for freshwater fishes electropherograms)
7: 27 (for chilling bulk quantities of freshwater smelt)
7: 33 (freshwater fish air-blast freezers)
S 978, 998 (respirometer)
980 (smokehouse for freshwater fishes)
999 (for testing toxicant avoidance by young salmon
1006 (air-lift pump for fish unloading)
1077 (eutectic brine freezer for Eskimo fishermen)

Aquaria
J 23(8): 1271 (for photography at sea)
(9): 1447 (small holding tank for fish)

Arai, Hisao P.
S 1010 (parasitic copepod *Parabomolochus cuneatus*)

Arctic, Canadian
S 988 (Eskimo commercial arctic char cannery)
1004 (marine-glacial relicts of islands)
1013 (zooplankton of Lake Hazen, Ellesmere Is.)
1077 (brine freezer for Eskimo fishermen)
1078 (walrus biology & economics)

Arctic Ocean (Canadian) (*see also* Oceanography)
B 152 (sea stars)

Argentine, Atlantic (*Argentine silus*)
J 23(8): 1145 (biology on Scotian Shelf)
B 154: 115 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)

Argentine silus (*see* Argentine, Atlantic)

Artemia salina
J 23(9): 1291 (used in *Euphausia pacifica* feeding experiments)

Ascophyllum (*see* Rockweeds)

Ascorbic acid
B 150: 15 (as inhibitor of albacore & tuna flesh "greening")

Ash content (*see* Mineral content)

Astacus astacus; *A. leptodactylus* (*see* Crayfish)

Asteroidea (*see* Sea stars)

Atheresthes stomias (*see* Flounder, arrowtooth)

Atlantic Ocean, northwestern (*see also* Oceanography)
J 23(1): 109 (demersal fish vertical migration)
B 155 (fishes of Canadian coast)

B

Bacillariophyta
J 23(3): 357 (thetin as dimethyl sulphide precursor)
(8): 1285 (dry weight, ash, & volume data for various)
(11): 1715 (of Lake Ontario surface waters)
S 1040 (enolase activity)

Bacteria (*see also Achromobacter*)
J 23(9): 1325 (*Gaffkya homari* incidence in lobsters)
(9): 1451 (identification of non-pathogens in lobsters)
(10): 1487 (*Aeromonas* antigens re trout disease)
(11): 1635 (in water & mud of P.E.I. oyster-bed area)

Bacteria in fish processing and products
J 23(8): 1281 (thermal resistance of *Corynebacterium* & a coccoid, from fish delicatessen)
CCG 7: (re keepability of fish sausage & wieners)

Balaenoptera acutorostrata (*see* Whale, minke)

Balaenoptera borealis (*see* Whale, sei)

Balaenoptera musculus (*see* Whale, blue)

Balaenoptera physalus (*see* Whale, fin)

Balanus (*see* Barnacle)

Barkley Sound, B.C.
S 1096 (lobsters transplanted to)

Barnacle
S 1041 (*Balanus nubilis* embryos guanosine derivatives)

Bass, largemouth (*Micropterus salmoides*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Bass, rock (*Ambloplites rupestris*)
J 23(1): 149 (alkaline phosphatase in scales)
(12): 1845 (mouth & body form re feeding ecology)

Bass, smallmouth (*Micropterus dolomieui*)
J 23(1): 149 (alkaline phosphatase in scales)
(6): 941 (feeding re indigenous walleye in a Man. lake)
(11): 1663 (muscle myogens & blood hemoglobins electropherograms)
CCG 7: 16 (protein electropherogram)

Bass, white (*Roccus chrysops*)
J 23(1): 149 (alkaline phosphatase in scales)
CCG 7: 16 (protein electropherogram)

Bathymetry (*see* Oceanography)

Bathypterois dubius (*see* Feelerfish, notch)

Beamish, Frederick William Henry
J 23(1): 109 (vertical migrations by demersal fish)
(3): 341 (swimming endurance of fish)
(10): 1507 (haddock fatigue and mortality)
S 1087 (fish reaction to otter trawls)

Beck, Brian
S 1084 (seal net fisheries)

Becker, Clarence Dale
J 23(12): 1965 (records of *Cryptobia salmositica* from sockeye salmon)

Behaviour (*see also* Activity; Diel habits; Light, reaction to; Migration; Salinity (reactions to); Schooling; Swimming; Temperature, water (reactions to); etc.)
J 23(1): 153 (of fish towards otter trawl)
(7): 1101 (of Lake Ainslie eels, N.S.)
(9): 1319 (mating, of Dungeness crab)
S 1054 (cod & haddock, re feed)

Benthos
J 23(12): 1875 (of 9 Rocky M. Trench SE B.C. lakes)

Berkeley, Cyril
S 1067 (B.C. Polychaeta)

Berst, Alfred Hewitt
J 23(2): 275 (comparative limnology)

Betaine (*see* Acids, amino)

Betts, John Le Roi
J 23(6): 813 (toxicity of kraft mill wastes)

Biely, Jacob
J 23(3): 395 (nutritive value of fish meals)

Bigeye (*see* Whiting (Pacific))

Bile duct (*see* Gall bladder)

Bilinski, Edward
J 23(2): 207 (lecithinase activity)
(6): 917 (salmon oil binding)

Billfish (*see* Saury, Atlantic)

Bilton, Hebert Thomas
J 23(6): 939 (pink salmon scales characteristics)
(9): 1403 (annulus formation)
CNS 16 (age composition of Pacific salmon)
CNS 27 (age composition of Pacific salmon catches)

Biotin (*see* Vitamin B group)

Bishop, Carol Marianne
J 23(10): 1607 (digestive tract of cod)
(12): 1841 (epithelial border of cod)

Black, Edgar Clark
J 23(1): 1 (blood of brook trout)
(4): 471 (metabolism in trout)
(6): 783 (effects of exercise on trout)
(8): 1187 (oxygen dissociation curves)
(9): 1461 (glycogen reserves of trout)
(10): 1575 (effect of hemolysis)
(10): 1581 (oxygen dissociation curves)

"Blackberry" condition in Atlantic cod (*see* Sulphur compounds)

Blackcod (*see* Sablefish)

Blackfish (*see* Ruff, black)

Blackfish, Cornish (*Centrolophus britannicus*)
J 23(8): 1161 (first western Atl. records; description & morphometry)

Blackford, Bradford Lloyd
J 23(9): 1411 (water circulation model)

Bligh, Emerson Graham
J 23(7): 1025 (cod muscle lipids)
(10): 1629 (blood lipids of the lobster)

Blood (*see also* Hemoglobin; Plasma; Serum)
J 23(1): 1 (respiratory function after brook trout seasonal temperature acclimation)
(4): 487 (thetin in Atlantic cod)
(4): 615 (new adrenal steroid from skates)
(7): 975 (starvation and refeeding of Atlantic cod: effects on constituents)
(8): 1109 (iron content in goldfish)
(8): 1187, (10): 1581 (respiratory function after Atlantic salmon seasonal temperature acclimation)
(9): 1325 (disease bacteria in lobster hemolymph)
(9): 1451 (non-pathogenic bacteria in lobster hemolymph)
(10): 1575 (oxygenation in Atl. salmons)
(10): 1599 (protein electropherograms of Salmonidae)
(10): 1629 (lipids of lobster)
S 978 (rainbow trout dorsal aortic pressure)

Blubber
S 972 (oil fatty types in gray seal & finback whale)
975, 976 (oil fatty acids types in finback whale)

Bluegill (*Lepomis macrochirus*)
J 23(11): 1663 (muscle myogens & blood hemoglobins electropherograms; *also* of hybrid with pumpkinseed)
(12): 1845 (mouth & body form re feeding ecology)
(12): 1923 (annual growth cycle, potential & compensation)

Bocaccio (*Sebastodes paucispinis*)
J 23(9): 1469 (range extension in N Pac.)
(12): 1981 (colour variant of B.C.)

Body proportions
J 23(12): 1845 (re mouth shape & feeding ecology of 14 freshwater fishes)

Bogoslowski, Anthony Steven
CCG 7 (keeping qualities of fish sausages and wieners)

Bordeleau, Michel André
J 23(9): 1465 (salinity tolerance levels)

Bosomworth, Neil John
J 23(9): 1461 (glycogen reserves of trout)

Boston, Noel Edward James
S 977 (isothermal surface layer of water)

Bothrocara brunneum (*see* Eelpout, twoline)

Bowfin (*Amia calva*)
CCG 7: 16 (protein electropherogram)
7: 33 (latent heat of freezing)

Boyce, Farrell MacKenzie
S 977 (isothermal surface layer of water)

Boyce, Gordon Alexander
J 23(10): 1587 (thiobarbituric acid values)

Boyd, John William
J 23(8): 1281 (thermal resistance of bacteria)

Brachydanio rerio (*see* Zebrafish)

Brachyura
CNS 15 (in NE Pac. Ocean salmonids stomachs)

Bradyidius saanichi (calanoid copepod)
J 23(6): 805 (new species, B.C.)

Brain
S 1073 (enzymes of Atlantic herring)

Brett, John Roland
J 23(9): 1447 (holding tank for fish)
S 978 (dorsal aortic pressures in trout)
998 (swimming energetics of salmon)

Brevibacterium incertum
J 23(9): 1451 (in lobster)

Brevoortia tyrannus (*see* Menhaden, Atlantic)

Brill (Pacific) (*Eopsetta jordani*) (petrale sole)
B 153 (population dynamics, B.C.)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
17 (age & length composition off Vancouver Is.)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Brining (*see also* Smoking)
CHN 27 (to reduce water loss from Atlantic cod fillets)

Bristol Bay, Alaska
J 23(3): 459 (sockeye salmon scale characteristics)

British Columbia (*see also* Georgia, Strait of; Oceanography, B.C. coast; *also* specific localities)
J 23(12): 1875 (limnology of 9 lakes in SE Rocky M. Trench)

Brockerhoff, Hans
J 23(12): 1835 (digestion of fat by cod)
S 985 (stereospecific analysis of triglycerides)
986 (preparation of L-α-glyceryl phosphoryl choline)
1028 (fatty acid distribution in triglycerides)
1029 (stereospecific analyses of vegetable fats)
1047 (triglyceride analysis)
1080 (Fatty acid distribution of animal of depot fats)

Bullhead, brown (*Ictalurus nebulosus*) (*Ameiurus nebulosus*)
J 23(12): 1845 (mouth & body form re feeding ecology)
B 151 (wiener-type sausage from)
CCG 7: 16 (protein electropherogram)

Bumpus, Dean Franklin
S 1109 (continental shelf water circulation)

Buoyancy
J 23(10) 1617 (adjustment by Atlantic salmon parr to water velocity)

Burbot (*Lota lota*) (freshwater cod; ling; maria)
B 151: 33 (canned smoked livers)
CCG 7: 16 (protein electropherogram)
7: 33 (latent heat of freezing)
S 1081 (sweet-cured smoked sliced products; recipe)

Bursa, Adam Stanislaw
S 1003 (*Kofoidinium arcticum*, new dinoflagellate)

Burt, James Robertson
J 23(4): 527 (enzymes of cod muscle)
(11): 1795 (Atlantic salmon muscle)

Buttkus, Hans
J 23(4): 563 (trout myosin)

C

Caeca, pyloric
J 23(10): 1607, (12): 1841 (Atlantic cod histology & morphology)

Calanoida
J 23(2): 189, (3): 415 (identification, key, etc. of free-swimming nauplii)
(6): 805 (new species: *Bradyidius saanichi*)

Cancer borealis (*see* Crab, Jonah)

Cancer irroratus (*see* Crab, rock)

Cancer magister (*see* Crab, Dungeness)

Canning; Canned products
J 23(6): 917 (effect on oil of sockeye salmon previously iced or partially frozen)
B 150 (nature of flesh "greening" discoloration during precooking of tuna)
151: 5, 29 (freshwater fish steaks, fillets, livers, etc.)
S 988 (arctic char in N.W.T.; operated by Eskimos)
991 (small-scale practical method for freshwater fishes)

Capelin (*Mallotus villosus*)
J 23(3): 463 (unusual occurrence in Bay of Fundy)
(7): 1099 (anal fin development)
B 151: 30 (canned smoked)
154: 106 (as Nfld. resource)
S 1053 (mass mortality re low sea temperatures)

Carassius auratus (*see* Goldfish)

Carbohydrates (*see also* Glycogen; Sugars)
S 1040 (metabolism of marine planktonic algae)

Carbon utilization (*see also* Productivity)
J 23(9): 1291 (*Euphausia pacifica*)

Carcharhinus falciformis (*see* Shark, sickle)

Carcharhinus longimanus (*see* Shark, whitetip)

Carcharhinus milberti (*see* Shark, sandbar)

Carcharhinus obscurus (*see* Shark, dusky)

Carp (*Cyprinus carpio*)
J 23(1): 149 (alkaline phosphatase in scales)
B 151 (smoked; sausage; wiener; fishballs)
S 1081 (sweet-cured smoked sliced products; recipe)

Carrothers, Percival John Godber
J 23(11): 1805 (current speed calibration curves)

Castell, Charles Howell
J 23(1): 27 (rancidity in lean fish muscle)
(5): 737 (TBA values from cod muscle)
(9): 1385 (rancidity in cod fillets)
(10): 1587 (thiobarbituric acid values)
CHN 27 (weight of fillets during processing & storage)
S 1068 (isometric monoethylenic fatty acids in herring oil)

Cat
S 1028, 1080 (fatty acids positional distribution in mesenteric fat triglycerides)

Catches; Landings (*see also* International Commission for the Northwest Atlantic Fisheries)
B 153: 43 (& catch per unit effort, B.C. petrale sole)
154 (Nfld. marine fishes)
CNS 14, 19 (& catch efforts, B.C. groundfish by areas and months, 1964, 1965)
16, 27 (age & length composition of B.C. sockeye, pink & chum salmon, 1964, 1965)
24 (sampling of B.C. commercial flatfishes by areas, 1946–65)
S 994 (catch equation re abundance & fishing success)
1089 (Atl. fishes in ICNAF areas)

Catfish, sea (*see* Wolffish, Atlantic)

Catostomus catostomus (*see* Sucker, longnose)

Catostomus commersoni (*see* Sucker, white)

Census
J 23(5): 769 (analysis of aerial, for ringed seals)

Centrolophus britannicus (*see* Blackfish, Cornish)

Centrolophus niger (*see* Ruff, black)

Cestoda (*see* Tapeworms)

Chalkiness of fish flesh
J 23(5): 673 (re flesh *p*H & free drip, in Pacific halibut)
(6): 925 (influence of fishing method on incidence in Pacific halibut)

Chan, Kai Sun
J 23(4): 575 (iron in natural waters)

Char, arctic (*Salvelinus alpinus*) (*Cristovomer alpinus*) (alpine trout)
J 23(10): 1599 (electropherograms of muscle myogen & hemoglobin)
B 154: 103 (as Nfld. resource)
S 988 (commercial canning by N.W.T. Eskimos)
1090 (description; biology; production)
1077 (eutectic brine freezer for Eskimo use)

Chicken (*see also* Feedstuff)
S 1028, 1080 (fatty acids positional distribution in pygostyle fat triglycerides)

Chilling (*see also* Sea water, refrigerated; Refrigeration)
CCG 7: 27 (bulk quantities of freshwater smelt to 32 F)

Chionoecetes opilio (*see* Crab, spider)

Chlamys islandicus (*see* Scallop, Iceland)

Chlorinity (*see* Oceanography; Waters, natural)

Chlorophyta (*see also* Sea-lettuce)
J 25(3): 357 (thetin as dimethyl sulphide percursor)
(8): 1285 (dry weight, ash & volume data for various)
(11): 1715 (of Lake Ontario surface waters)
S 1040 (enolase activity)

Cholesterol (*see* Sterols)

Choline
J 23(7): 1025 (phosphatidyl, of fresh vs. frozen Atlantic cod muscle)
S 986 (simplified preparation of glyceryl phosphoryl)

Chondrus crispus (*see* Irish moss)

Choroszucha, Czeslawa
J 23(11): 1653 (chemical composition of crayfish)

Chromatography, gas (*see also* Acids, fatty)
S 984 (effect of concentration on retention times of fatty acid esters mixture minor components)

1048 (simplified, for marine animal oil fatty acid esters)

Chromosomes (*see* Cytology)

Chrysophyceae
J 23(11): 1715 (of Lake Ontario surface waters)
S 1040 (enolase activity)

Chub
B 151 (canned steak, fillets; smoked; sausage; wiener)

Chub, creek (*Semotilus atromaculatus*)
J 23(5): 623 (association with brook trout in Pennsylvania streams)

Chub, peamouth (*Mylocheilus caurinum*)
J 23(6): 929 (electropherogram of multiple hemoglobins)

Cisco (*Coregonus artedeii* (lake herring) (*see also* Tullibee)
J 23(1): 149 (alkaline phosphatase in scales)

Cisco, arctic (*Coregonus autumnalis*)
J 23(1): 141 (distinction from *C. laurettae*; distribution; origin)

Citharichthys sordidus (*see* Sanddab, mottled)

Claggett, Freddie Gene
CVG 36 (spontaneous heat in B.C. herring meal)

Clam, butter (*Saxidomus giganteus*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)
S 1095 (brief description; biology; B.C. production)

Clam, horse (*Tresus capax*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)

Clam, Japanese (*see* Clam, Manila)

Clam, littleneck (*Protothaca staminea*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)
S 1095 (brief description; biology; B.C. production)

Clam, Manila (*Venerupis japonica*) (Japanese clam)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)
S 1095 (brief description; biology; B.C. production)

Clam, mud (*Mya arenaria*) (softshell clam)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)

Clam, razor (*Siliqua patula*)
S 1095 (brief description; biology; B.C. production)

Clam, softshell (Atlantic) (*Mya arenaria*)
B 154: 127 (possible Nfld. resource)

Clam, softshell (Pacific) (*see* Clam, mud)

Clams, (B.C. in general)
S 1095 (brief descriptions; biology; production)

Clarke, Livingston Wilberforce
J 23(10): 1599 (muscle myogen patterns)
(11): 1663 (comparative electropherograms)

Cleaning and dressing fish
S 992 (practical method for freshwater fishes)

Climate
J 23(2): 276 (re lake whitefish year-class strength)

Clingfish, kelp (*Rimicola muscarum*)
J 23(8): 1277 (B.C. range extension)

Clinocardium nuttallii (*see* Cockle, basket)

Clupea harengus herangus (*see* Herring, Atlantic)

Clupea pallasii (*see* Herring, Pacific)

Cobalamins
S 996 (synthesis & properties of 2 coenzyme B_{12} analogues)

Cobalt compounds (*see* Cobalamins)

Coble, Daniel W.
J 23(1): 15 (growth and temperature)
(1): 149 (alkaline phosphatase in fish scales)

Cockle, basket (*Clinocardium nuttallii*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)

Cod (Atlantic) (*Gadus callarias*)
J 23(4): 527 (glycogenolytic enzymes of muscle)

Cod, Atlantic (biology) (*Gadus morhua*)
J 23(1): 109 (vertical migration in NW Atl. Ocean)
(3): 341 (swimming endurance re speed & temperature)
(4): 487 (incorporation of a thetin from zooplankton feed)
(6): 909 (exopthalmia mechanism of eye)
(7): 975 (starvation & refeeding effect on liver & blood constituents)
(8): 1249 (steroid transformations by Stannius corpuscles)
(9): 1465 (tolerance levels to low salinity)
(10): 1607 (digestive tract morphology)
(11): 1809 (unusual fatty acids composition in lipids of one specimen)

(12): 1835 (degradation of ingested fats during digestion)
1841 (epithelial border histology of ileum, pyloric caeca, & rectum)
B 154: 1, 27, 154 (as Nfld. resource)
CJG 13: 1 (Nfld. & Labrador cod catches, surveys, gear catches, etc.)
CSG 46 (changes in S Gulf of St. Lawrence fishery & biology)
S 997 (international otolith exchange for comparing age determinations)
1019 (random vs. stratified sampling for age and growth of inshore)
1020 (otter-trawl selectivity & girth–length relationships)
1021 (age validity from otoliths)
1022 (trends in fishery off E Nfld. & Labrador)
1023, 1024, 1025, 1089 (ICNAF Canadian research reports)
1052, 1053, 1059, 1060 (behaviour, catches, etc. re low sea temperatures in Nfld. & Grand Bank areas)
1054 (behaviour & concentrations re feed in Nfld. & Labrador areas)
1075 (evolution of southern Gulf of St. Lawrence fishery)
1087 (behaviour towards otter trawl, observed photographically)

Cod, Atlantic (products)
J 23(1): 21 (liver decomposition effect on liver oil free fatty acids)
(1): 27 (amino acids, antioxidants, & pro-oxidants effect on muscle rancidity)
(1): 155 (irradiation effect on liver re liver oil free fatty acids)
(3): 357, (4): 487 (dimethyl sulphide odour from zooplankton thetin ingested by fish)
(5): 737, (10): 1587 (iron salts effect on test for muscle rancidity)
(5): 775 (equilibrium moisture values of fresh & salt)
(6): 921 (nucleotide interference with glycogen determination in red & white muscle)
(7): 1025 (muscle lipids of fresh vs. cold-stored)
(7): 1063 (palatability of fillets after single & double freezing)
(7): 1083 (deck sampling of research vessel catches)
(9): 1385 (oxidative rancidity in frozen stored fillets)
B 154: 1, 27 (as Nfld. resource)
CHN 23 (holding partially frozen, between 25 & 30 F)
24 (acceptability of freeze-dried steaks)
S 972 (fatty acids types in liver & flesh oil)
1034 (dimethyl sulphide odour from ingested zooplankton)
1043 (ante-mortem effects of activity on post-mortem quality of muscle)
1080 (fatty acids positional distribution triglycerides)

Cod, black (*see* Sablefish)

Cod, freshwater (*see* Burbot)

Cod, gray (*see* Cod, Pacific)

Cod, Pacific (*Gadus macrocephalus*) (gray cod)
J 23(3): 319 (salinity & temperature re embryonic development)
(5): 701 (partial freezing for preservation)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, & used for reduction, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Colour (*see* Pigments)

Competition
S 1025 (re feed & predator control ICNAF area)

Composition (biological)
J 23(11): 1715 (Lake Ontario surface waters phytoplankton)

Composition (chemical and physical)
J 23(8): 1285 physical, of 28 phytoplankton species)
(9): 1353 (chemical, changes in pink salmon at sea)
(11): 1653 (re nutrition value of American crayfish meat)
B 151: 2 (proximate analyses of freshwater fishes)
S 1004 (waters of 6 Canadian arctic lakes)

Computer technique
S 1050 (age distribution from age–length keys & length distributions)

Conservation
S 1008 (harp & hood seals)
1018 (review of possible actions for ICNAF area)

Continental Shelf (*see also* Oceanography)
S 1109 (surface circulation, Nfld. to Florida)

Cooper, Edwin Lavern
J 23(5): 623 (fecundity of brook trout)
(5): 775 (equilibrium values of cod)

Copepoda
J 23(1): 85 (in feed of NE Pac. Ocean salmons & steelhead trout)
(2): 189, (3): 415 (descriptions, key, etc. of nauplii of free-swimming)
(4): 539 (re spring primary productivity in E subarctic Pacific)
CNS 15, 20, 21, 22, 23 (in NE Pac. Ocean salmonids stomachs)

S 1004 (*Limnocalanus macrurus*) re Canadian Arctic Islands marine-glacial relicts)
1013 (*Cyclops scutifer*, Lake Hazen, N.W.T.)

Copepoda, parasitic
J 23(4): 521 (*Sphyrion lumpi* reproduction)
S 1010 (*Parabomolochus cuneatus* on shiner seaperch gills)

Copper compounds
J 23(1): 27, (9): 1385 (pro-oxidant effect on Atlantic cod muscle)
S 999 (sublethal Cu–Zn pollution re young salmon & insect larvae)

Coregonus artedii (*see* Cisco)

Coregonus autumnalis (*see* Cisco, arctic)

Coregonus clupeaformis (*see* Whitefish, lake)

Coregonus laurettae (*see* Cisco, arctic)

Cornick, John Walter
J 23(9): 1325 (incidence of *Gaffkya homari*)
(9): 1451 (hemolymph of lobster)

Corynebacterium
J 23(8): 1281 (heat resistance of)

Coryphaena hippurus (*see* Dolphin)

Coscinodiscus concinnus (diatom)
S 989 (growth-rate determination technique)

Cottus bairdi (*see* Sculpin, mottled)

Cottus cognatus (*see* Sculpin, slimy)

Cow
S 1028 (fatty acids positional distribution in subcutaneous fat triglycerides)

Crab, deep sea red (*Geryon quinquedens*)
CSG 50 (description)

Crab, Dungeness (*Cancer magister*) (*see also* Crabs (Pacific))
J 23(9): 1319 (premating & mating behaviour)
S 1041 (embryo guanosine derivatives)

Crab, Jonah (*Cancer borealis*)
CSG 50 (description; potential)

Crab, king (*Paralithodes camtschatica*)
J 23(5): 729 (fishery effect on populations size-class structure)

Crab, northern stone (*Lithodes maia*)
CSG 50 (description)

Crab, rock (*Cancer irroratus*)
B 154: 122 (as Nfld. resource)
CSG 50 (description, distribution, abundance, size, fishery, meat yield, potential)

Crab, spider (*Chionoecetes opilio*)
B 154: 122 (as Nfld. resource)
CSG 50 (description, life history, distribution, abundance, size, fishery, meat yield, potential)

Crab, toad (*Hyas araneus*)
CSG 50 (description)

Crabs (Atlantic) (*see also* names of species)
CSG 50 (descriptions, life history, size, distribution, abundance, & as resource, fresh & canned)

Crabs (Pacific) (*see also* names of species)
CNS 14, 19 (B.C. trawl-caught landings, 1964, 1965)

Crappie, black (*Pomoxis nigromaculatus*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Crassostrea gigas (*see* Oyster, Pacific)

Crassostrea virginica (*see* Oyster, Atlantic)

Crayfish (*Astacus astacus* and *A. leptodactylus*)
J 23(11): 1658 (composition of meats, as reared in Poland)

Crayfish, American (*Orconectes limosus*)
J 23(11): 1653 (chemical composition re nutritive value of meat, as reared in Poland)

Crecy, Lake N.B.
J 23(11): 1799 (eels, re trout production)

Cristovomer (*Salvelinus*) (*see* Char, arctic; Trout)

Crop, standing
J 23(2): 263 (lake whitefish, Georgian Bay, Ont.)

Crustacea (*see also* common names of species)
S 1041 (*Daphnia magna* encysted embryos nucleotides)
1107 (distribution of decapod, in NW Atl.)

Cryptobia salmositica (flagellate)
J 23(12): 1965 (first record of parasitic in sockeye salmon)

Cryptophyceae
S 1040 (enolase activity)

Crysophyta
J 23(3): 357 (thetin as dimethyl sulphide precursor)

Cucin, Daniel
J 23(2): 221 (lake whitefish)

Culture, tissue
J 23(4): 595 (of Atlantic oyster cardiac tissue)

Curing (*see also* Delicatessen)
S 1081 (sweet-cured smoked sliced products from freshwater fishes)

Currents (*see also* Oceanography; Tides)
J 23(6): 852 (re dynamics of NE Pac. Ocean water masses)
(9): 1411 (electrical analog model for Gulf of St. Lawrence wind-driven)
(11): 1805 (speed calibration curves for histogram sea current meter)
S 1109 (surface, on Continental Shelf from Nfld. to Florida)

Cyclopoida
J 23(2): 189, (3): 415 (identification, key, etc., of free-swimming nauplii)

Cyclops species (Copepoda)
S 1013 (C. scutifer, Lake Hazen, N.W.T.)

Cyclopterus lumpus (*see* Lumpfish)

Cyema atrum (*see* Snipe-eel, bobtail)

Cymatogaster aggregata (*see* Seaperch, shiner)

Cyprinus carpio (*see* Carp)

Cystophora cristata (*see* Seal, hooded)

Cytology (*see also* Eggs, fish)
J 23(4): 521 (*Sphyrion lumpi* ova)
(5): 767 (simple technique for obtaining chromosomes)

D

Dabrowski, Teofil
J 23(11): 1653 (chemical composition of crayfish)

Dace, blacknose (*Rhinichthys atratulus*)
J 23(5): 623 (association with brook trout in Pennsylvania streams)

Dace, longnose (*Rhinichthys cataractae*)
J 23(5): 623 (association with brook trout in Pennsylvania streams)

Dace, umpqua (*Rhinichthys evermanni*)
J 23(5): 767 (simple technique for obtaining chromosomes)

Dale, Jacqueline
J 23(4): 487 (dimethyl-β-propiothetin in cod)

Daphnia magna
S 1041 (nucleotides of encysted embryos)

Davenport, Douglas
J 23(12): 1981 (salmon rockfish Sebastodes paucispinis)

Decapoda (*see also* certain individual names of)
J 23(8): 1135 (NE Pac. oceanic shrimps depth distribution)
S 1107 (distribution in NW Atl.)

Deformity (*see* Abnormalities)

Dehadrai, Padmakar Vishvanath
J 23(6): 909 (exopthalmia in cod)

Delicatessen (*see also* Fishballs; Sausage, fish)
J 23(8): 1281 (thermal resistance of bacteria from processed fish spread)
B 151 (from freshwater fishes)
S 1081 (sweet-cured smoked sliced products from freshwater fishes)

Density of natural waters (*see* Limnology; Oceanography)

Deoxyribonucleic acid (*see* Acids, nucleic)

Depth
S 1057, 1058 (distribution of haddock, re sea temperature)
1058 (distribution of Atlantic cod, re sea temperature)

Development (*see also* Eggs, fish; Growth)
J 23(3): 319 (rate of Pacific cod eggs & larvae)
(8): 1121 (brook & rainbow trout embryos re oxygen & temperature)
(10): 1537 (rate of trouts re vertebral number)

Diatoms
S 972 (*Skeletonema costatum* oil fatty acids separation & types)
989 (determination technique for growth rate of chain-forming)

Dickie, Lloyd Merlin
J 23(6): 869 (food & growth of fishes)
(8): 1209 (food & growth of fishes)
S 994 (abundance & fishing success)

Diel habits
J 23(4): 499 (yellow perch activity under ice)
(8): 1259 (changes in adult Nicola L. kokanee, B.C.)
(11): 1761 (longnose & white suckers, Sixteenmile L., B.C.)

Digestion; Digestive tract
J 23(10): 1607 (Atlantic cod morphology)

Dilworth, Carole Lola Ryan
J 23(10): 1617 (buoyancy in salmon)

Dingle, John Reginald
S 1043 (glycolytic metabolites in cod muscle)

Dinoflagellata
J 23(8): 1265 (*Gonyaulax acatenella* re shellfish toxicity)

S 1003 (new species: *Kofoidinium arcticum*)

Dinophyta
J 23(3): 357 (thetin as dimethyl sulphide precursor)
(11): 1715 (of Lake Ontario surface waters)
S 1040 (enolase activity)

Dips
S 1031 (containing antibiotic for fish & fillets)

Discoloration (*see* Pigments)

Disease
J 23(9): 1325 (*Gaffkya homari* in lobsters)
(10): 1487 (antigens for treating trout "redmouth")
S 1002 (virus tumors in Pac. flatfishes skin)

Dispersal (*see* Distribution; Migration; Movements)

Distribution (biological) (*see also* Marking; Migration; Movements; Tagging)
J 23(1): 141 (Arctic ciscoes)
(4): 499 (vertical, of yellow perch under ice)
(7): 1043 (oceanic, of fin-marked pink salmon)
(8): 1135 (vertical, of NE Pac. oceanic shrimps)
(11): 1673 (bathymetric, of Oregon sea stars)
(12): 1977 (factors, re brook trout associated with young Atlantic salmon)
B 152 (Canadian arctic & subarctic sea stars)
S 973 (NE Pac. Ocean offshore coho salmon)
974 (Pac. salmon across NE Pac.)
1008 (harp & hood seals)
1057 1058 (Haddock, re depth, season & temperature)
1059 (Atlantic cod, re depth & temperature)
1067 (range extensions of B.C. Polychaeta)
1107 (decapod Crustacea in NW Atl.)
1108 (N American arctic & subarctic sea stars)

Diving, scuba or skin (*see* Observation, underwater)

Docherty, Georgina Elizabeth
J 23(9): 1461 (glycogen reserves of trout)

Dog
S 1028, 1080 (fatty acids positional distribution in mesenteric fat triglycerides)

Dogfish, Pacific (*Squalus suckleyi*)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, & livers by months, 1964, 1965)

Dogfish, spiny (*Squalus acanthias*)
J 23(1): 153 (underwater observation in off-bottom trawl)
B 154: 113 (as Nfld. resource)
S 1053 (mass mortality re low sea temperatures)

Doidge, Dolores Agnes
CNS 20, 21, 22, 23 (food of salmonids)

Dollinger, Edward
J 23(5): 673 (chalkiness in halibut)
(5): 701 (fish preservation by partial freezing)
(6): 925 (chalkiness in halibut)

Dolly Varden (*Salvelinus malma*)
J 23(6): 929, (10): 1599 (muscle myogens & multiple hemoglobin electropherograms)

Dolphin (*Coryphaena hippurus*)
CSG 49 (identification)

Dolphin, Risso (*Grampus grieseus*) (gray grampus)
S 1001 (first B.C. record)

Donaldson, Lauren R.
S 1061 (Alaska salmon resource)

Drinnan, Roy Ellis
J 23(4): 595 (cultivation of oyster cells)
CSG 48 (oyster stocks)

Drip
J 23(5): 673 (& flesh *p*H re Pacific halibut flesh chalkiness)
(7): 1077 (on thawing Atlantic cod fillets)
CHN 27 minimization of, by brining Atlantic cod fillets)

Driver, Edwin Andrew
J 23(11): 1815 (meristic numbers of yellow perch)

Drum, freshwater (*Aplodinotus grunniens*) (sheepshead)
J 23(1): 149 (alkaline phosphatase in scales)
B 151 (canned; sausage; wiener; fishballs)
CCG 7: 1 (keepability of sausage & wiener)
S 1081 (sweet-cured smoked sliced products; recipe)

Duck
S 1028 (fatty acids positional distribution in pygostyle fat triglycerides)

Dugong
S 1079 (faunal succession from extinct form)

Dulse (*Rhodymenia palmata*)
J 23(6): 915 (vitamins B in)

Dyer, William John
J 23(6): 921 (glycogen in cod muscle)
(7): 1063 (quality of frozen cod)
(12): 1821 (iced and frozen swordfish)
S 1043 (glycolytic metabolites in cod muscle)

Dymond, John Richardson
J 23(5): 779 (obituary of)

E

Eales, John Geoffrey
J 23(10): 1617 (buoyancy in salmon)

Eaton, Catherine Anne
J 23(7): 991 (Atlantic herring oils)
S 975, 976 (lipids of the fin whale)

Echinodermata (*see* Sea stars)

Echo sounding (*see* Sounding, echo)

Ecology
J 23(12): 1845 (of feed re mouth & body form in freshwater fishes)
B 152: 51 (N American arctic & subarctic sea stars)

Economics
B 154 (of Nfld. fishery resources)
S 1018 (re possible ICNAF area conservation actions)

Eel, American (*Anguilla rostrata*) (common eel)
J 23(7): 1101 (behaviour records in Lake Ainslie, N.S.)
(11): 1799 (re trout production in Crecy Lake, N.B.)
B 151 (canned; smoked fillets)
154: 104 (as Nfld. resource)

Eel, bobtail snipe (*see* Snipe-eel, bobtail)

Eelpout, twoline (*Bothrocara brunneum*)
J 23(2): 309 (first B.C. coastal record)

Eggs, fish (*see also* Cytology; Fecundity; Maturation; Spawning; Reproduction)
J 23(3): 319 (Pacific cod: factors affecting development)
(7): 1037 (resistance of zebrafish immature embryos after damage to membrane)
(8): 1121 (brook & rainbow trout: development re oxygen & temperature)
(11): 1761 (incubation period, of longnose & white sucker)

Electrophoresis; Electropherograms
J 23(1): 101 (re *Onchorhynchus* inter-species relationships)
(6): 929 (micro starch gel apparatus & technique for multiple hemoglobins separation)
(10): 1599 (of Salmonidae muscle myogens & blood proteins)
(11): 1653 (of American crayfish meat amino acids)
(11): 1663 (comparison of muscle myogens & hemoglobin plasma of several fish families)
CCG 7: 16 (re identifying freshwater fish species)
S 1073 (Atlantic herring lactate dehydrogenase)

Elliott, John Malcolm
J 23(1): 157 (downstream movements of trout fry)

Ellis, Derek Victor
J 23(2): 181 (swimming speed of salmon)

Elson, Paul Frederick
S 999 (sublethal copper-zinc pollution in a salmon river)
1083 (Atlantic salmon scales)

Embryology (*see* Cytology; Eggs, fish)

Emery, Alan Roy
J 23(8): 1145 (Atlantic argentine)

England, Lucas Allison
CSG 48 (oyster stocks)

Enhydra lutris (*see* Otter, sea)

Enolase (*see* Enzymes)

Enzymes (*see also* Electrophoresis)
J 23(1): 149 (alkaline phosphatase in various fish scales)
(2): 207, (11): 1811 (lecithinase activity & distribution in rainbow trout muscle)
(4): 527 (glycogenolytic in Atlantic cod muscle)
(6): 909 (carbonic anhydrase re Atlantic cod exopthalmia)
S 996 (synthesis of 2 coenzyme B_{12} analogs)
1011 (of salmon milt for nucleoside di- & triphosphate synthesis)
1036 (systems in fish)
1040 (marine phytoplankton enolase activity)
1042 (of *Achromobacter cholinophagum* oxidizing betaine)
1049 (lingcod muscle guanine deaminase)
1073 (lactate dehydrogenase & aspartate aminotransferase in Atlantic herring tissues)

Eopsetta jordani (*see* Brill (Pacific))

Epithelial cells
J 23(12): 1841 (bordering Atlantic cod ileum, pyloric caeca & rectum)

Epizootic
S 1002 (re Pac. flatfishes epithelial tumors)

Erie, Lake (*see also* Great Lakes)
J 23(2): 275 (Long Point Bay comparative summer limnology)

Erignathus barbatus (*see* Seal, bearded)

Escolar (*Lepidocybium flavobrunneum*)
CSG 49 (identification)

Eskimos
S 988 (commercial canning of arctic char)
1061 (Alaska salmon fishing)
1077 (brine freezer for fishermen)
1078 (role of walrus to)

Esox lucius (*see* Pike, northern)

Esox masquinongy (*see* Maskinonge)

Esters (*see* Acids, fatty; Lipids)

Estuary
J 23(11): 1803 (spawning of Atlantic salmon)

Eubalaena glacialis (*see* Whale, right)

Eumetopias jubata (*see* Sea lion, northern)

Euphausia pacifica (*see* Euphausiids)

Euphausiids
J 23(1): 85 (in feed of NE Pac. Ocean salmons & steelhead trout)
(9): 1291 (feeding, growth, respiration, etc. of *Euphausia pacifica*)
CNS 15, 20, 21, 22, 23 (in NE Pac. Ocean salmonids stomachs)

Euthynnus pelamis (*see* Tuna, skipjack)

Exercise (*see* Activity)

Exophthalmia ("pop-eye") (*see* Eye)

Exploitation
J 23(2): 221 (Georgian Bay lake whitefish)
(3): 349 (in a predator-prey relationship type)
(10): 1553 (mathematical methods of estimating populations)
S 994 (abundance re catch equation & fishing success)
1008 (harp & hood seals)

Exploration
CNG 73 (for groundfish in Hecate Strait)

Eye
J 23(6): 909 (exopthalmia mechanism in Atlantic cod)
S 1073 (enzymes of Atlantic herring)

F

Faber, Daniel James
J 23(2): 189 (free-swimming copepod nauplii)
(3): 415 (nauplii in Narragansett Bay)

Falcon Lake, Man.
J 23(6): 941 (feeding of indigenous walleye re introduced smallmouth bass)

Falkner, Neil Ward
J 23(8): 1109 (thermal shock in goldfish)

Fangtooth (*Anoplogaster cornuta*) (Ogrefish)
J 23(2): 305 (new NE Pac. Ocean record)

Farming, fish
CHN 26 (summary of non-Canadian practices for marine fish)

Fat (*see* Acids, fatty; Oils and fats, marine animal; Phospholipids; Triglycerides)

Fatigue (*see* Activity)

Fatness (condition)
J 23(6): 797 (in southern Nfld. herring population)

Fatty Basin, B.C.
S 1096 (transplantation of lobsters to)

Fauna, marine mammal
S 1078 (faunal succession of extinct N. Pac.)

Fecundity
J 23(2): 243 (lake whitefish, Georgian Bay)
(5): 623 (of brook trout in infertile Pennsylvania streams)
S 1051 (possible effects of low sea temperature on haddock)

Fedoruk, Alex Nicholas
J 23(6): 941 (feeding habits of walleye & bass)

Feed (*see also* Hunger concept; Predation; Starvation effect)
J 23(1): 85 (of NE Pac. Ocean salmons & steelhead trout)
(4): 487 (thetin incorporation from, in Atlantic cod)
(6): 869, (8): 1209 (re growth of fishes)
(6): 941 (walleye re smallmouth bass in a Man. lake)
(8): 1259 (seasonal & diel changes, of adult kokanee)
(9): 1291 (of *Euphausia pacifica*)
(9): 1331 (sensing of position, by surface ripples perception through lateral line organs)
(10): 1495, 1523 (consumption re pike growth & maintenance)
(10): 1621 (of redfish in captivity)

(12): 1845 (re mouth & body form of 14 freshwater fishes)
(12): 1971 (re mouth anatomy of pelagic shrimps)
CNS 15, 20, 21, 22, 23 (of NE Pac. Ocean salmonids)
S 1000 (Pac. salmons in ocean)
1024: 26 (Atlantic cod)
1025 (re competition & predator control, ICNAF area)
1054 (cod & haddock re behaviour & concentrations)
1062, 1063, 1064 (B.C. salmons; sockeye; pink; chum)
1078 (walrus)

Feedstuff
CNS 14, 19 (B.C. landings of groundfish for, by areas, 1964, 1965)

Feelerfish, notch (*Bathypterois dubius*)
J 23(5): 715 (NW Atl. record & species status review)

Fellowships
MSP 8 (Board facilities for postdoctorate tenure)

Fertility (*see* Fecundity)

Fillets (*see also* Muscle; Preservatives)
J 23(4): 487 (odours from sulphur compounds ingested by Atlantic cod)
(7): 1063 (palatability of Atlantic cod, after single & double freezing)
(9): 1385 (oxidative rancidity in frozen stored, of Atlantic cod)
B 151 (canned smoked, of freshwater fishes)
CHN 27 (weight gain & loss during processing & storage)
S 993 (practical preparation & freezing, freshwater fishes)
1031 (antibiotic dips for)
1043 (quality re antemortem activity of Atlantic cod & postmortem glycolysis)

Fins
J 23(7): 1099 (development of capelin anal)
(12): 1845 (re body form of 14 freshwater fishes)
(12): 1969 (second record of accessory, on northern pike)

Fishballs (delicatessen)
B 151: 34 (recipe formulas for freshwater fishes)

Fisheries
B 153: 4 (history of Canadian & U.S.A. petrale sole)
S 1022 (trends for cod off E Nfld. & Labrador)
1037 (international: re biology, systematics, fishermen, law, communications, etc.)
1075 (evolution of S Gulf of St. Lawrence cod)

Fisheries Research Board of Canada
AR 1964 (Annual Report: Board members; function & organization; trends affecting work; 1964 research highlights, 1964–65 expenditures; Board Act)
R 1964 (Review: Board members; organization; establishments; reviews of investigations by establishments; list of 1964 publications & reports; professional staffs by establishments; index to professional staff)

Fishes, list of and identification
B 154: 168 (list of names of Nfld.)
155 (Atl. coast of Canada)

Fishing methods (*see* Catches; also types of gear, e.g. Net; Trawl)

Fishmeals
J 23(3): 395 (protein nutrient quality)
CVG 36 (antioxidants control of B.C. herring)

Flagellata
J 23(12): 1965 (first records of *Cryptobia salmositica* in sockeye salmon)

Flatfishes, Atlantic (*see also* Groundfish, Atlantic; *also* names of species)
CJG 13 (Nfld. catch statistics, etc.)
S 1023, 1024, 1089 (ICNAF Canadian research reports)

Flatfishes, Pacific (*see also* Groundfish, Pacific; *also* names of species)
CNS 14, 19 (B.C. landings by areas, & dispositions, 1964, 1965)
24 (sampling B.C. commercial catches by areas, 1946–65)
S 1002 (virus tumors in skin)

Flavour of products (*see* Quality of products)

Fleming, Allister Melville
CJG 13 (investigations & groundfish landings in Nfld.)
S 1019 (age & growth in Nfld. inshore cod fishery)
1052 (cod growth & temperature in Nfld. area)
1060 (cod availability in St. Mary's Bay, Nfld.)

Flesh (*see also* Chalkiness; Fillets; Muscle; Protein)
S 1031 (treatment with antibiotics as preservative)

Flora (*see also* Seaweeds; Vegetables)
S 1012 (list of vascular plants around Ogac Lake, N.W.T.)

Flounder, arrowtooth (*Atheresthes stomias*) (arrowtooth sole; turbot)
CNG 73 (in Hecate Strait exploratory fishing)

CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Flounder, starry (*Platichthys stellatus*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Flounder, winter (*Pseudopleuronectes americanus*)
J 23(1): 109 (day & night variations in catch size)
(3): 341 (swimming endurance re speed & temperature)
B 154: 116 (as Nfld. resource)
S 1087 (behaviour towards otter trawl, observed photographically)

Flounder, witch (*Glyptocephalus cynoglossus*) (Graysole; witch)
J 23(1): 109 (day & night variations in catch size)
B 154: 4, 85 (as Nfld. resource)
CJG 13: 26 (Nfld. fishery; age length)
S 1023, 1024 (ICNAF Canadian research reports)

Flounder, yellowtail (*Limanda ferruginea*) (yellowtail)
J 23(1): 109 (day & night variations in catch size)
B 154: (as Nfld. resource)
S 1024 (ICNAF Canadian research report)

Flukes (Trematoda)
S 981 (*Cercaria patellae*) larvae infesting limpet)

Fofonoff, Nickolas Paul
J 23(6): 825 (Pac. oceanographic conditions)

Foley, Diane Mary
S 1030 (anesthetics for the mature lobster)

Food, of animals (*see* Feed; Feedstuff)

Forecast
B 154: 146 (of future of Nfld. marine fisheries; also for individual species on other pages)

Formaldehyde
S 1027 (effect on length & weight of preserved Atlantic herring)

Forrester, Clifton Roger
J 23(3): 319 (Pacific cod)
(4): 511 (size limit of sole)
B 153 (population of petrale sole)
CNS 17 (length & age composition of petrale sole)
18 (length & age composition of rock sole)
24 (market samples of B.C. groundfish landings)

Forss, Carl Albert
J 23(8): 1135 (oceanic shrimps)

Fossils (*see* Palaeontology)

Fraser, Doris Isabel
J 23(6): 921 (glycogen in cod muscle)
(12): 1821 (iced & frozen swordfish)

Fraser River, B.C.
J 23(4): 575 (iron compounds in, & distribution in adjacent marine waters)

Freeman, Harry Cleveland
J 23(8): 1249 (corpuscles of Stannius of cod)

Freeze-drying
B 151: 25 (freshwater fish products)
CHN 24 (Atlantic cod: advantages & disadvantages re acceptability)

Freezing (*see also* Refrigeration)
J 23(5): 701 (partial, for Pac. groundfish preservation)
(6): 917 (effect of partial, on oil of subsequently canned sockeye salmon)
(7): 1025 (of Atlantic cod: effect on muscle lipids)
(7): 1063 (single & double: effect on Atlantic cod fillet palatability)
(12): 1821 (re swordfish muscle quality)
CCG 7: 33 (air-blast freezers for freshwater fishes; freezing rate; latent heat of freezing)
CHN 23 (partial, of Atlantic cod, between 30 & 25 F)
S 993 (practical method for dressed & filleted freshwater fish)
1077 (eutectic brine freezer for Eskimo fishermen)

Freshwater fish and products (*see also* names of freshwater fishes)
J 23(12): 1845 (mouth & body form re feeding ecology)
B 151 (preparation, processing, recipes, etc. for specialty products)
CCG 7 (seven articles on various)
S 980 (brining & smokehouse data)
990 (practical salting procedure)
991 (practical small-scale canning method)
992 (practical cleaning & dressing method)
993 (practical freezing dressed & filleted)
1081 (sweet-cured smoked sliced products; recipes)

Frog (*Rana pipiens*)
S 1028 (fatty acids positional distribution in fat triglycerides)

Fry (*see* names of adult fish, e.g., Salmon)

Fucus (*see* Rockweeds)

Fundulus diaphanus (*see* Killifish, banded)

Fundulus notatus (*see* Topminnow, blackstripe)

Fundy, Bay of
J 23(3): 463 (unusual occurrence of capelin)
S 1026 (1964 another cold sea temperature year)

G

Gadus callarias (*see* Cod (Atlantic))

Gadus macrocephalus (*see* Cod, Pacific)

Gadus morhua (*see* Cod, Atlantic)

Gaffkya homari (bacteria)
J 23(9): 1325 (incidence in lobsters)
(9): 1451 (identification of associated bacteria in lobsters)

Gall bladder
J 23(10) 1607 (Atlantic cod morphology)

Garside, Edward Thomas
J 23(8): 1121 (development of trout embryos)
(10): 1537 (developmental rate in salmonids)
(11): 1815 (meristic numbers of yellow perch)

Gear, fishery (*see* types of gear, e.g. Net; Trawl)

Geen, Glen Howard
J 23(11): 1761 (sucker life histories)

Geiger, Shirley Evelyn
J 23(5): 673 (chalkiness in halibut)
(5): 701 (fish preservation by partial freezing)
(6): 925 (chalkiness in halibut)

Geomorphology
J 23(8): 1197 (of sea floor around Magdalen Is.)

Georgia, Strait of
J 23(4): 511 (appropriate lemon sole size limits)
(4): 575 (distribution of iron compounds from Fraser R.)
(8): 1265 (*Gonyaulax acatenella* bloom re shellfish toxicity)

Georgian Bay, Ont.
J 23(2): 221 (lake whitefish dynamics & exploitation)

Gerking, Shelby D.
J 23(12): 1923 (growth in bluegill sunfish)

Geryon quinquedens (*see* Crab, deep sea red)

Gibson, Robert John
J 23(7): 1007 (Atlantic salmon behaviour)
(12): 1977 (distributions of trout & salmon)

Giovando, Lawrence Frank
J 23(4): 539 (spring phytoplankton bloom)

Glazing
B 151: 26 (frozen freshwater fish products)

Globicephala melaena (*see* Whale, pilot)

Globulins (*see* Serum, blood)

Glossary
B 152: 69 (terms descriptive of sea stars)
155: 430 (terms descriptive of Canadian Atl. marine fishes)

Glucose
J 23(1): 65 (rainbow trout activity effect on metabolism of)
(7): 975 (effect of starvation & refeeding on levels in Atlantic cod)
S 1036 (phosphates)

Glycerides (*see* Acids, fatty; Lipids; Oils and fats)

Glycogen, glycolysis
J 23(4): 471, (9): 1461 (re exercised rainbow trout metabolism)
(4): 527 (glycogenolytic enzymes in Atlantic cod muscle)
(6): 909 (re Atlantic cod exopthalmia)
(6): 921 (nucleotide interference with estimation of in Atlantic cod muscle)
(7): 975 (Atlantic cod liver: effects of starvation & refeeding)
S 1043 (antemortem activity effect on postmortem quality of Atlantic cod fillets)

Glyptocephalus cynoglossus (*see* Flounder, witch)

Glyptocephalus zachirus (*see* Sole, rex)

Godfrey, Harold
S 973 (coho salmon in offshore B.C. waters)

Goldeye (*Hiodon alosoides*)
B 151 (smoked)
CCG 7: 33 (latent heat of freezing)
S 980 (brining time before smoking)

Goldfish (*Carassius auratus*)
J 23(8): 1109 (hematological responses to sublethal thermal shock)
S 983 (lethal heat shock effect on water balance)
1028, 1080 (fatty acids positional distribution in fat triglycerides)

Gonads (*see also* Eggs, fish; Maturation; Milt)
S 1073 (enzymes of Atlantic herring)

Gonatus fabricii (see Squid, arctic)

Gonyaulax (protozoan flagellates) (*see* Shellfish occasional toxicity)

Goosefish (*see* Monkfish)

Goudie, Carol
J 23(3): 395 (nutritive value of fish meals)

Grainger, Edward Henry
B 152 (arctic sea stars)
S 1017 (Labrador Asteroidea)
1108 (North American sea stars)

Grampus, gray (*see* Dolphin, Risso)

Grampus griseus (*see* Dolphin, Risso)

Grampus orca (*see* Whale, killer)

Grand Bank, off Nfld.
J 23(5): 651 (American plaice sexual maturity & spawning)
S 1051, 1052, 1054, 1055, 1057, 1058 (haddock & cod re low sea temperatures, feed, etc.)
1053 (mass mortalities of various fishes due to low sea temperatures)

Grayling, arctic (*Thymallus arcticus*)
S 1015 (Great Slave L. sport fishing)

Graysole (*see* Flounder, witch)

Great Bear Lake, N.W.T.
J 23(7): 963 (limnology)
S 1005 (temperature regime)

Great Slave Lake, N.W.T.
S 1015 (sport fishing survey & facilities)

Great Lakes (*see also* Georgian Bay; *also* names of lakes)
CCG 7: 21 (plans for extension of sea lamprey control to lower lakes)

"Greening"
B 150 (of albacore & tuna flesh during precooking before canning: cause, tests for, & inhibitors)

Greenland
S 1035, 1082, 1102 (salmon fishery of western)

Grenadier, roughhead (*Macrourus berglax*)
B 154: 116 (as Nfld. resource)

Grey- (*see* Gray-)

Grinols, Richard Byron
J 23(2): 305 (range extensions of *Anoplogaster cornuta* and *Cyema atrum*)
(6): 935 (southern range of *Acantholiparis opercularis*)

Groundfish, Atlantic (*see also* names of species)
CJG 13 (Nfld. & Labrador catches, surveys, gear catches, etc.)
S 1023, 1024 (ICNAF Canadian research reports)

Groundfish, Pacific (*see also* names of species)
J 23(4): 611 (design of side-trawling type of otter trawl)
(5): 701 (partial freezing as preservation means)
CNG 73 (Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. efforts & landings & dispositions, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Groups, Atlantic and Pacific Oceanographic, of Fisheries Research Board
R 1964 (locations; professional staffs; reviews of 1954 investigations)

Growth (*see also* Development)
J 23(1): 15 (total annual of yellow perch, re temperature)
(2): 163 (mathematical method of fitting curves to data)
(2): 248 (rate of lake whitefish, Georgian Bay, Ont.)
(6): 797 (in southern Nfld. herring population)
(6): 869, (8): 1209 (re feed of fishes)
(7): 947 (salmon parr in Nabisipi R., Que.)
(8): 1145 (Atlantic argentine on Scotian Shelf)
(9): 1291 (*Euphausia pacifica*)
(10): 1495 (re pike feed consumption & maintenance)
(10): 1621 (of redfish in captivity)
(12): 1923 (bluegill sunfish characteristics)
B 153: 108 (B.C. petrale sole)
S 989 (determination technique for rate of, in chain-forming diatoms)
1019 (random vs. stratified sampling for Atlantic cod)
1052 (Nfld. area cod re sea temperatures)

Gruchy, Charles George
J 23(9): 1457 (longear sunfish)

Guanine
J 23(7): 1095 (in coho salmon belly-skin pigments)
S 1049 (lingcod muscle deaminase)

Guiguet, C.J.
S 1001 (first B.C. record of *Grampus griseus*)

Guilbault, Raymond
J 23(9): 1465 (salinity tolerance levels)

Gulland, John Alan
S 1018 (ICNAF area conservation actions)

Gunnel, red (*Pholis schultzi*)
J 23(2): 313 (first B.C. coastel record)

H

Haddock (biology) (*Melanogrammus aeglefinus*)
J 23(1): 109 (vertical migrations in NW Atl. Ocean)
(10): 1507 (muscular fatigue re mortality in otter-trawled)
B 154: 3, 55, 154 (as Nfld. resource)
CJG 13: 21 (Nfld. surveys)
S 1023, 1024, 1089 (ICNAF Canadian research reports)
1051 (sea temperature effects on fecundity)
1053 (mass mortality from low sea temperatures in Nfld. area)
1054 (behaviour & concentrations re feed)
1055 (successful year-classes re year-class success of other fishes)
1057, 1058 (distribution on Grand Bank re season, depth & temperature)
1087 (behaviour towards otter trawl, observed photographically)

Haddock, Jerusalem (*see* Opah)

Haedrich, Richard Lee
J 23(8): 1161 (family Centrolophidæ)

Hake, Pacific (*Merluccius productus*)
CNG 73 (in Hecate Strait exploratory fishing)

Hake, silver (*Merluccius bilinearis*)
B 154: 115 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)

Hake, white (*Urophycis tenuis*)
B 154: 109 (as Nfld. resource)

Halibut, Atlantic (*Hippoglossus hippoglossus*)
B 154: 4, 87 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)
1080 (fatty acids positional distribution in triglycerides)

Halibut, Greenland (*Reinhardtius hippoglossoides*) (turbot)
J 23(2): 309 (first B.C. coastal record)
B 154: 89, 154 (as Nfld. resource)
CJG 13: 27 (Nfld. landings; length distribution)
S 1053 (mass mortality re low sea temperatures)

Halibut, Pacific (*Hippoglossus stenolepis*)
J 23(5): 673 (free drip & flesh *p*H re flesh chalkiness)
(5): 701 (partial freezing for preservation)
(6): 925 (influence of fishing method on flesh chalkiness incidence)
CNG 73 (in Hecate Strait exploratory fishing)
S 1080 (fatty acids positional distribution in triglycerides)
1091 (short description; biology; B.C. fishery)

Halichoerus grypus (*see* Seal, gray)

Hammerhead, scalloped (*Sphyrna lewini*)
CSG 47 (identification)

Hammerhead, smooth (*Sphyrna zygaena*)
CSG 47 (identification)

Hammond, Brian Ralph
J 23(1): 65 (metabolism in trout)

Hanavan, Mitchell Grattan
S 974 (offshore distribution of salmon)

Harling, Wayne Robert
J 23(4): 611 (groundfish trawl net)
(12): 1967 (pygmy rockfish, *Sebastodes wilsoni*)

Harpacticoida
J 23(2): 189, (3): 415 (identification, key, etc. of free-swimming nauplii)

Hart, John Lawson
S 1024 (Atl. fisheries research; a review)
1098 (American smelt)

Hartman, Gordon Frederick
J 23(11): 1761 (sucker life histories)

Hashish, Salah Eldin
J 23(4): 601 (preservation by irradiation)

Hasler, Arthur Davis
J 23(4): 499 (perch distribution)
(9): 1331 (functions of lateral line)

Hassan, Y.N.
J 23(4): 601 (preservation by irradiation)

Hatchery (*see also* Management; Trout)
J 23(2): 268 (planting effects on lake whitefish)
S 1039 (lobster)

Hayashi, Koichiro
J 23(6): 783 (effects of exercise on trout)

Hazen, Lake (Ellesmere Is., N.W.T.)
S 1013 (limnology; zooplankton; *Cyclops scutifer*)

Heart (*see also* Blood)
J 23(4): 595 (in vitro cultivation of Atl. oyster cardiac tissue)
S 1073 (enzymes of Atlantic herring muscle)

Heat, latent (of freezing)
CCG 7: 38 (of 10 freshwater fishes)

Hecate Strait, B.C.
CNG 73 (exploratory fishing for groundfish)

Heinicke, Elizabeth Anne
S 983 (water balance in goldfish)

Hemilepidotus spinosus (*see* Irish lord, brown)

Heming Lake, Man.
J 23(11): 1807 (pugheadedness in northern pike & yellow perch)
CCG 7: 9 (whitefish improvement through pike & *Triaenophorus* control)

Hemitripterus americanus (*see* Sea raven, Atlantic)

Hemoglobin (*see also* Blood)
J 23(1): 45 (mountain whitefish hematology)
(6): 783 (changes in exercised rainbow trout)
(6): 929, (10): 1599, 1663 (electropherograms of various fishes multiple types)
(8): 1109 (responses to sublethal thermal shock in goldfish)
(9): 1385 (iron content pro-oxidant effect on frozen cod fillets)
(10): 1575, 1581 (hemolysis effect on oxygen uptake in *Salmo*)
B 150 (role in "greening" of albacore & tuna flesh during precooking before canning)

Hergenrader, Gary Lee
J 23(4): 499 (perch distribution)

Herring, Atlantic (*Clupea harengus harengus*)
J 23(6): 797 (biological characteristics of S Nfld. population)
(7): 991 (fatty acid composition of oils)
(10): 1587 (lipid oxidation test)
B 154: 90 (as Nfld. resource)
CJG 13: 37 (Nfld. investigations; length composition)
S 972 (fatty acids types in flesh oil)
1023, 1024 (ICNAF Canadian research reports)
1027 (formalin preservation vs. cold storage effect on length & weight)
1073 (lactate dehydrogenase & aspartate aminotransferase)
1103 (brief description, life history, etc.)

Herring, Lake (*see* Cisco)

Herring, Pacific (biology) (*Clupea pallasi*)
J 23(1): 153 (underwater observation in off-bottom trawl)
CNG 74 (1965 B.C. spawn deposition)
S 1094 (description; life history; B.C. fishery; management; feed)

Herring, Pacific (products)
J 23(3): 395 (protein nutrient quality of fishmeal)
(5): 681 (pilot plant fractionation of methyl esters from oil)
CVG 36 (antioxidants control of spontaneous heating)
S 987 (concentrating highly unsaturated fatty acid methyl esters)
1068 (oil isomeric monoethylenic fatty acids)
1080 (fatty acids positional distribution in triglycerides)

Hickman, Cleveland Pendelton, Jr.
J 23(1): 65 (metabolism in trout)

High, William Louis
J 23(1): 153 (underwater observation in off-bottom trawl)

Hines, James Alexander
S 1043 (glycolytic metabolites in cod muscle)

Hingley, Helen Joyce
J 23(4): 487 (dimethyl-β-propiothetin in cod)

Hiodon alosoides (*see* Goldeye)

Hippoglossoides elassodon (*see* Sole, flathead)

Hippoglossoides platessoides (*see* Plaice, American)

Hippoglossus hippoglossus (*see* Halibut, Atlantic)

Hippoglossus stenolepis (*see* Halibut, Pacific)

Histology (*see also* Cytology)
J 23(4): 595 (Atlantic oyster cardiac tissue)
(6): 909 (Atlantic cod eye, re exopthalmia)
(12): 1841 (epithelial border of Atlantic cod ileum, pyloric caeca & rectum)
(12): 1913 (histopathology of inflammation induced in Pacific oyster)
S 1002 (Pac. flatfishes epithelial tumors)

History (*see also* Life history)
B 153: 4 (Canadian & U.S.A. petrale sole fishery)
154: 12 (of Nfld. marine fisheries research)
155: 4 (Canadian Atl. coast ichthyology)

Hodder, Vincent Mackay
J 23(7): 1083 (deck sampling of catches)
S 1020 (catchability of cod)
1023 (trends in Nfld. cod fishery)
1051 (temperature vs. fecundity of Grand Bank haddock)
1057 (haddock distribution on Grand Bank)

1058 (haddock distribution on St. Pierre Bank)
1069 (American shad in Nfld. waters)

Hogenkamp, Henricus Petrus Cornelius
S 996 (synthesis & properties of 2′,5′-dideoxyadenosylcobalamin and 5′-deoxythylmidyclobalamin)

Holley, Richard Alan
S 1030 (anesthetics for lobster studies)

Holmberg, Deanne Marie
CNS 14 (B.C. landings of trawl-caught groundfish)
19 (1964 B.C. landings of trawl-caught groundfish)

Homarus americanus (*see* Lobster)

Homing (*see also* Migration; Spawning)
S 1062, 1063, 1064 (B.C. salmons: sockeye; pink; chum)

Hormones
J 23(4): 615 (new adrenal steroid from skates blood)
(8): 1249 (steroid transformations by Atlantic cod Stannius corpuscles)

Horse
S 1028, 1080 (fatty acids positional distribution in flesh fat triglycerides)

Houston, Arthur Hillier
J 23(8): 1109 (thermal shock in goldfish)
S 983 (water balance in goldfish)

Hoyle, Richard James
S 1028 (fatty acid distribution in triglycerides)

Hudson Bay and James Bay
B 152 (sea stars)

Humphreys, Robert David
J 23(3): 463 (Capelin in Bay of Fundy)
(6): 797 (Nfld. herring population)
S 1103 (Atlantic herring)
1104 (Atlantic mackerel)
1027 (effect of storage on herring)

Hunger concept (*see also* Feed; Starvation effect)
J 23(5): 689 (re depensatory process of sockeye salmon)

Hunter, John Gerald
S 1090 (arctic char)

Hunter, John Roe
J 23(4): 547 (schooling behavior)

Huron, Lake (*see* Georgian Bay; Great Lakes)

Hussein, M.F.
J 23(4): 601 (preservation by irradiation)

Hyas araneus (*see* Crab, toad)

Hybrids
J 23(11): 1663 (bluegill × pumpkinseed hemoglobin electropherogram)
(12): 1845 (bluegill × pumpkinseed mouth & body form)

Hydrocarbons
S 995 (fundamental groups in flame ionization detectors response to oxygenated aliphatic)

Hydrodynamics
S 998 (of sockeye salmon re swimming energy)

Hydrography (*see also* Oceanography)
J 23(8): 1197 (of sea floor around Magdalen Is.)

Hydrolagus colliei (*see* Ratfish)

Hyperprosopon ellipticum (*see* Surfperch, silver)

Hypoxanthine
J 23(7): 1095 (in coho salmon belly-skin pigments)
(11): 1795 (in muscle of chill-stored Atlantic salmon)
(12): 1821 (formation in swordfish muscle re quality)

I

Ice
S 1031 (containing antibiotic, for fish holding)

ICNAF (*see* International Commission for the Northwest Atlantic Fisheries)

Ictalurus nebulosus (*see* Bullhead, brown)

Identification (*see also* Electrophoresis; Keys; *also* names of organisms)
B 155 (Canadian Atl. marine fishes)

Idler, David Richard
J 23(4): 615 (1α-hydroxycorticosterone)
(6): 915 (vitamins B in dulse (*Rhodymenia palmata*))
(7): 1063 (quality of frozen cod)
(8): 1249 (corpuscles of Stannius of cod)
S 1071 (cholesterol glucopyranosiduronate)
1072 (sterols in Irish moss)

Ileum
J 23(12): 1841 (epithelial border histology in Atlantic cod)

Illex illecebrosus (*see* Squid)

Illumination (*see also* Light, reactions to)
J 23(4): 539 (at photosynthesis critical depth)

Inconnu (*Stenodus leucichthys*)
B 151 (canned)
CCG 7: 33 (latent heat of freezing)
S 1015 (Great Slave L. sport fishing)

Indiana State, U.S.A.
J 23(12): 1923 (bluegill sunfish growth characteristics in 8 lakes)

Inflammation
J 23(12): 1913 (histopathology of induced, in Pacific oyster adductor muscle)

Inosine
J 23(12): 1821 (formation in swordfish muscle re quality)

INPFC (*see* International North Pacific Fisheries Commission)

Insecticides
S 1007, 1085 (re Atlantic salmon & trout)

Insects, aquatic
S 999 (various fly larvae as indicators of Cu–Zn toxicity in Atlantic salmon streams)

International Commission for the Northwest Atlantic Fisheries (ICNAF)
B 154 (re Nfld. marine fisheries resources)
S 997 (cod otolith exchange for age determination comparisons)
1018 (review of possible conservation actions)
1019 (inshore cod age & growth studies sampling comparisons)
1020 (otter-trawl selectivity re cod girth–length relationships)
1021 (age validity from cod otoliths)
1022 (trends in cod fishery off E Nfld. & Labrador)
1023, 1024, 1089 (Canadian research reports)
1025 (data lack for calculating maximum sustained yields)
1026 (1964 another cold sea temperature year)
1027 (length & weight changes of herring stored frozen vs. in formalin)
1051 (haddock fecundity re sea temperature effects)
1052, 1060 (cod growth re Nfld. area sea temperatures)
1053 (mass mortality of Nfld. area fish re low temperatures)
1054 (cod & haddock behaviour & concentrations re feed)
1055 (haddock successful year-classes on Grand Bank re year-class success of fish to N & E)
1056 (sea & air temperature anomalies off Nfld.)
1057, 1058 (haddock distribution re season, depth & temperature)
1059, 1060 (cod research catches re depth & temperature)

International North Pacific Fisheries Commission (INPFC)
S 973 (offshore coho salmon biology)
974 (offshore biology of 5 salmon species)
1038 (progress in 1964 Canadian high-seas salmon research)
1062, 1063, 1064 (life history review of B.C. sockeye; pink; chum salmons)

Intestine
J 23(10): 1067 (Atlantic cod morphology)

Iodine value
S 1045 (empirical relation re polyunsaturated fatty acid content of various marine animal oils & lipids)

Ionization, flame
S 995 (fundamental groups response of oxygenated aliphatic hydrocarbons)

Iredale, David Gordon
S 1081 (sweet-cured freshwater fish)

Irish lord, brown (*Hemilepidotus spinosus*)
J 23(8): 1277 (B.C. records & first Alaska record)

Irish moss (*Chrondrus crispus*)
B 154: 144 (as Nfld. resource)
CJG 13: 49 (Nfld. preliminary experimental harvesting)
S 1072 (cholesterol & related sterols in)

Iron compounds
J 23(4): 575 (determination & amounts in Fraser R. water & during its mixing in adjacent seawaters)
(5): 737, (10): 1587 (effect on fish muscle thiobarbituric acid values)
(8): 1109 (content in goldfish blood)
(9): 1385 (pro-oxidant effect on frozen Atlantic cod fillets)

Irradiation
J 23(1): 155 (effect on Atlantic cod livers re oil free fatty acid)
(4): 601 (by gamma rays for sardine preservation)

Ishida, Teruo
S 974 (offshore distribution of salmon)

Isopoda
S 1004 (*Mesidothea entomon glacialis* re Canadian Arctic Islands marine-glacial relicts)

Isopsetta isolepis (*see* Sole, butter)

Isotopes
J 23(2): 207 (carbon for tracing lecithinase activity)
(4): 601 (cobalt for preservative irradiation)
(9): 1291 (carbon in algae for determining *Euphausia pacifica* carbon utilization)

S 1036 (in biochemical synthesis & degradation studies of fishes)

Istiophorus albicans (*see* Sailfish)

Isurus oxyrinchus (*see* Mako)

Ivlev, Viktor Sergeevich
J 23(11): 1727 (biological productivity of waters)

J

Jackfish (*see* Pike, northern)

Jahn, Lawrence Allan
J 23(10): 1475 (movements of trout)

Jangaard, Peter Michael
J 23(1): 21 (free fatty acids in cod oil)
(5): 681 (fractionation of marine oils)
(9): 1385 (rancidity in cod fillets)
(11): 1809 (fatty acid lipids from cod)
CHN 26 (salt water fish farming)
S 975, 976 (lipids of the fin whale)
987 (concentrating esters in marine lipids)

Japan
S 974: 6 (Pac. salmons fishery)

Jenkinson, Donald William
J 23(7): 1089 (salmon scales)
CNS 16 (age composition of B.C. salmon)
27 (age composition of B.C. salmon catches)

Johnson, Lionel
J 23(7): 963 (circulation of Great Bear Lake)
(10): 1495 (pike food)
S 1004 (marine-glacial relicts)
1005 (temperature regime of deep lakes)

Johnson, Waldo Eugene
S 982 (self-regulation of population abundance in *Oncorhynchus nerka*)

Jonas, Richard Edmund Ernest
J 23(2): 207 (lecithinase activity)
(11): 1811 (lecithinase in trout muscle fractions)

Jones, Noel Rees
J 23(11): 1795 (hypoxanthine in salmon muscle)

Jones, Ronald Leroy
J 23(5): 767 (technique to obtain chromosomes from fishes)

Juan de Fuca, Strait of
J 23(4): 575 (distribution of iron compounds from Fraser R.)

Junge, Charles Oscar
J 23(5): 689 (depensatory process based on hunger)

K

Kalmakaff, James
S 1040 (algae enolase)

Kamra, Saroja Keshav
J 23(7): 975 (starvation & refeeding of cod)

Kanazawa, Akio
J 23(6): 915 (vitamins B in dulse)

Katz, Max
J 23(12): 1965 (records of *Cryptobia salmositica* from sockeye salmon)

Keast, Allen
J 23(12): 1845 (mouth & body form in fish)

Keenleyside, Miles Hugh Alston
J 23(7): 1007 (Atlantic salmon behaviour)

Keepability (*see also* Feezing; Refrigeration)
CCG 7: 1 (freshwater fish vs. meat sausage & wieners)

Keleher, James John
S 1015 (Great Slave Lake fishing)

Kelps
B 154: 145 (*Laminaria* & *Agarum* as Nfld. resources)

Kendall's *tau*
S 1070 (computer method for calculating with ungrouped data)

Kerekes, Joseph
J 23(10): 1625 (measuring plankton biomass)

Kerr, Robert Bews
J 23(6): 929 (micro starch gel electrophoresis)

Ketchen, Keith Stuart
B 153 (population of petrale sole)
S 1002 (studies on virus diseases of fishes)

Keys
J 23(2): 189 (free-swimming copepod nauplii)
B 152: 1 (arctic & subarctic N American sea stars)
155 (Canadian Atl. marine fishes)

Kidney
J 23(8): 1249 (steroid transformations by Stannius corpuscles)
S 1073 (enzymes of Atlantic herring)

Killifish, banded (*Fundulus diaphanus*) (freshwater mummichog)
J 23(12): 1845 (mouth & body form re feeding ecology)

Kirkpatrick, Donald
J 23(1): 1 (blood of brook trout)
(8): 1187 (oxygen dissociation curves)
(10): 1575 (effect of hemolysis)
(10): 1581 (oxygen dissociation curves)

Knight, William Rexford
S 1070 (computerizing Kendall's *tau* method)

Kodiak Island, Alaska
J 23(5): 729 (fishery effect on king crab populations structure)

Kohler, Allan Carl
J 23(10): 1621 (growth of redfish)
CSG 46 (St. Lawrence cod fishery)
S 997 (cod otolith)
1075 (la pêche à la morue dans le golfe Saint-Laurent)

Kokanee (*Oncorhynchus nerka*) (landlocked sockeye salmon)
J 23(8): 1259 seasonal & diel changes in feed of adult)

Kolakowski, Edward
J 23(11): 1653 (chemical composition of crayfish)

Kuril, Lake (U.S.S.R.)
J 23(3): 459 (sockeye salmon scale characteristics)

Kwain, Wen-Hwa
J 23(7): 983 (trout response to light)

L

Labidesthes sicculus (*see* Silverside, brook)

Laboratories, Fisheries Research Board of Canada
R 1964 (locations; professional staffs; reviews of 1964 investigations)

Labrador (*see also* Newfoundland region)
S 1017 (sea stars)
1022 (cod fishery trends)
1054 (cod & haddock behavior & concentrations re feed)

Lactic acid; Lactate
J 23(1): 65, (4): 471, (6): 783, (9): 1461 (re exercised rainbow trout metabolism)
S 1073 (lactate dehydrogenase in Atlantic herring)

Laishley, Edward James
J 23(7): 1063 (quality of frozen cod)

Lakes (*see* Limnology; Waters, natural; also names of individual lakes)

Laminaria (*see* Kelps)

Lamna nasus (*see* Porbeagle)

Lampetra lamottei (*see* Lamprey, American brook)

Lamprey, American brook (*Lampetra lamottei*) (*Entosphemus lamottenii*)
J 23(11): 1663 (muscle myogens electropherograms)

Lamprey, sea (*Petromyzon marinus*)
J 23(2): 241 (predation on lake whitefish, Georgian Bay, Ont.)
(11): 1663 (muscle myogens & blood plasma electropherograms)
B 151: 6 (freshwater: canned smoked)
CCG 7: 21 (advance control plans from Lake Superior to lower Great Lakes)

Lampris regius (*see* Opah)

Lancetfish (*Alepisaurus ferox*)
CSG 49 (identification)

Landings (*see* Catches)

Lang, Grant Wells
J 23(6): 917 (salmon oil binding)

Lantz, Andrew William
B 151 (freshwater fish)
CCG 7 (chilling freshwater smelt in quantity)
7 (air-blast freezers for freshwater fish)
S 980 (method for brining and smoking fish)
988 (fish cannery in N.W.T.)
990 (method for salting fish)
991 (method for canning freshwater fi)sh
992 (cleaning & dressing fish)
993 (freezing fish)
1077 (eutectic brine freezer for Eskimo fishermen)
1081 (sweet-cured freshwater fish)

Larkin, Peter Anthony
J 23(3): 349 (predator-prey relationship)
S 1037 (review of international fisheries)

Lasker, Reuben
J 23(9): 1291 (*Euphausia pacifica*)

Lateral line organs
J 23(9): 1331 (role in topminnow surface-wave perception)
(11): 1811 muscle lecithinase distribution in rainbow trout muscle)

Launce, inshore (*Ammodytes hexapterus*)
B 154: 116 (as Nfld. resource)

Launce, northern sand (*Ammodytes dubius*)
B 154: 116 (as Nfld. resource)

Lauzier, Louis Marcel
S 1026 (ocean water temperature)
1109 (Atl. continental shelf water circulation)

Lawler, George Herbert
J 23(11): 1807 (pugheadedness in perch and pike)
(12): 1969 (accessory fin of pike, *Esox lucius*)
CCG 7 (pike control)

LeBrasseur, Robin John
J 23(1): 85 salmon and trout stomach contents)
(4): 539 (spring phytoplankton bloom)
CNS 15 (stomach contents of salmonids in northeastern Pac. Ocean)
20, 21, 22, 23 (food of salmonids)

Lecithinase (*see* Enzymes)

Leim, Alexander Henry
B 155 (fishes of Atl. coast)

Length (*see also* Size)
J 23(1): 15 (increase of yellow perch re temperature)
S 1027 (change in Atlantic herring frozen vs. stored in formalin)

Length composition (*see also* Size)
J 23(6): 797 southern Nfld. herring population)
B 153: 79 (B.C. petrale sole stocks)
CNS 16, 27 (1964 & 1965 B.C. sockeye, chum & pink salmon catches)
17 (petrale sole off Vancouver Is.)
18 (Hecate Strait rock.sole)

Length-frequency (*see also* Size)
J 23(3): 463 (Bay of Fundy capelin)
(11): 1761 (longnose & white suckers Sixteenmile L., B.C.)
S 1050 (computer technique for determining age distribution from age–length keys & length distributions)

Length–weight ration (*see also* Size)
J 23(2): 245 (lake whitefish, Georgian Bay, Ont.)
(5): 623 (brook trout in infertile Pennsylvania streams)
(6): 797 (southern Nfld. herring population)
B 152: 94 (B.C. petrale sole stocks)

Lepidocybium flavobrunneum (*see* Escolar)

Lepidopsetta bilineata (*see* Sole, rock)

Lepomis gibbosus (*see* Pumpkinseed)

Lepomis macrochirus (*see* Bluegill)

Lepomis megalotis (*see* Sunfish, longear)

Leptoclinus maculatus (*see* Shanny)

Lethal limits (*see* Pollution; Temperature, water (reactions to); Toxicants)

Leucichthys species (*see* Cisco)

Leung, Ted C.
S 1073 (enzymes in herring)

Li, Ming Fang
J 23(4): 595 (cultivation of oyster cells)

Life history (*see also* names of organisms)
J 23(3): 365 (characteristics variations in steelhead trout)
(8): 1145 (Atlantic argentine on Scotian Shelf)
(11): 1761 (longnose & white sucker, Sixteenmile L., B.C.)
B 154 (of many Nfld. marine fishes, etc.)
S 973 (offshore NE Pac. Ocean coho salmon)
1062, 1063, 1064 (review of B.C. sockeye; pink; chum salmons)
1090 (arctic char)

Light, and reactions to (*see also* Illumination)
J 23(1): 157 (downstream migrating brown trout)
(2): 293 (re aggregations of chum salmon fry)
(7): 983 (re rainbow trout seeking overhead cover)
(7): 1007 (young Atlantic salmon & brook trout)

Limacina (*see* Pteropoda)

Limanda aspera (*see* Sole, yellowfin)

Limanda ferruginea (*see* Flounder, yellowtail)

Limnology
J 23(2): 275 (summer, of Long Point Bay, Lake Erie, Ont.)
(7): 963 (Great Bear Lake, N.W.T.)
(10): 1625 (efficiency if suspended biomass estimation methods)
(11): 1715 (Lake Ontario surface waters phytoplankton)
(12): 1875 (comparative, of 9 Rocky Mt. Trench SE B.C. lakes)
(12): 1923 (comparative, of 8 Indiana lakes)
S 1013 (Lake Hazen, N.W.T.)

Limpet (*Patella vulgata*)
S 981 (infestation with trematode fluke larvae)

Lindsey, Casimir Charles
J 23(11): 1761 (sucker life histories)

Ling (*see* Burbot)

Lingcod (*Ophiodon elongatus*)

Lingcod (*Ophiodon elongatus*)
J 23(5): 701 (partial freezing for preservation)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)
S 1049 (muscle guanine deaminase)

Liparid, spiny-cheek (*Acantholiparis opercularis*)
J 23(6): 935 (description of new record)

Liparis mucosus (*see* Snailfish, slimy)

Lipids (*see also* Acids, fatty; Oils and fats, marine animal; Phospholipids)
J 23(5): 737, (10): 1587 (Fe effect on test for oxidation of)
(7): 1025 (effect of Atlantic cod frozen storage on muscle)
(7): 1077 (total, in thawed Atlantic cod fillets)
(9): 1353 (content of pink salmon at various life-historystages)
(10): 1629 (lobster blood)
S 985 (stereospecific analysis of human depot fat triglycerides)
1045 (polyunsaturation re iodine values of various marine animal oils)

Lippa, Erich Johannes Richard
CNS 14 (B.C. landings of trawl-caught groundfish)

Lithodes maia (*see* Crab, northern stone)

Liver
J 23(1): 21 (effect of decomposition of Atlantic cod, on liver oil free fatty acids)
(1): 155 (effect of irradiation of Atlantic cod, on liver oil FFA)
(4): 471, (9): 1461 (glycogen re exercised rainbow trout metabolism)
(7): 975 (starvation & refeeding effect on constituents, Atlantic cod)
(10): 1587 (Fe effect on lipid oxidation)
B 151: 33 (canning of smoked burbot)
CNS 14, 19 (B.C. landings by months, 1964, 1965)
S 972 (fatty acid types in oils of Atlantic cod & squid)
1073 (enzymes of Atlantic herring)

Lo, Eddie
J 23(6): 921 (glycogen in cod muscle)

Lobster (*Homarus americanus*)
J 23(9): 1325 (incidence of *Gaffkya homari* disease bacteria)
(9): 1451 (identification of non-pathogenic bacteria interfering with tests for *Gaffkya homari* in lobsters)
(10): 1629 (blood lipids)
B 154: 116 (as Nfld. resource)
CJG 13: 40 (Nfld.: biological sampling)
S 1028, 1080 fatty acids positional distribution in hepatopancreas fat triglycerides)
1030 (general anesthetics for)
1039 (conservation, trap regulations, hatcheries, etc.)
1076 (Canadian & American offshore trap & trawl investigations)
1096 (transplantation to Barkley Sound, B.C.)
1106 (general description; life history, etc.)

Lohnes, Dianne Paulette
J 23(12) 1821 (iced & frozen swordfish)

Lophius americanus (*see* Monkfish)

Loring, Douglas Howard
J 23(8): 1197 (sea-floor conditions)

Lorz, Harold William
J 23(8): 1259 (food of kokanee)

Lota lota (*see* Burbot)

Ludwig, Sigrid Agnes Marie
J 23(9): 1403 (annulus formation)
CNS 16 (age composition of B.C. salmon)

Lumpfish (*Cyclopterus lumpus*)
B 154: 115 (as Nfld. resource)

Lusz, Larry Dean
J 23(1): 154 (underwater observation in off-bottom trawl)

Lyopsetta exilis (*see* Sole, slender)

M

MacCallum, Wallace Allison
J 23(7): 1063 (quality of frozen cod)

Mackerel, Atlantic (*Scomber scombrus*)
J 23(10): 1587 (lipid oxidation test)
B 154: 93 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)
1053 (mass mortality re low sea temperatures)
1104 (brief description; biology, etc.)

Mackereljack (*Trachurus symmetricus*)
J 23(4): 547 (schooling behaviour analysis procedure)

MacLean, Jill
J 23(1): 27 (rancidity in lean fish muscle)

Macrourus berglax (*see* Grenadier, roughhead)

Macrozoarces americanus (see Pout, ocean)

Magdalen Islands, Gulf of St. Lawrence
J 23(8): 1197 (sea floor conditions in vicinity)

Maintenance
J 23(10): 1495 (re pike feed consumption & growth)

Makaira albicans (*see* Marlin, white)

Makaira nigricans (*see* Marlin, blue)

Mako (*Isurus oxyrinchus*)
CSG 47 (identification)

Malacostraca (*see Mysis relicta; Pontoporeia affinis*)

Mallotus villosus (*see* Capelin)

Malpeque Bay, P.E.I.
J 23(11): 1635 (nutrient & energy cycles re oysters)

Mammals, marine (*see also* names of various kinds)
S 1028, 1080 (fatty acids positional distribution in depot fat triglycerides)
1079 (faunal succession from extinct N Pac. forms)

Man
S 985, 1028, 1080 (fatty acid positional distribution in depot fat triglycerides)

Management (*see also* International Commission for Northwest Atlantic Fisheries; International North Pacific Fisheries Commission)
B 153: 166, 187 (B.C. & U.S.A. petrale sole fishery)
S 1007, 1085 (Atlantic salmon & brook trout research & management program)

Manitoba (*see also* Heming Lake; *also* names of fishes)
J 23(11): 1815 (meristic numbers in yellow perch of saline lakes)

Manning, Glenville Thomas
J 23(6): 783 (effects of exercise on trout)

Mansfield, Arthur Walter
S 1078 (walrus in Canadian arctic)

Manzer, James Ivan
S 974 (offshore distribution of salmon)
1000 (sea life of Pacific salmon)

March, Beryl Elizabeth
J 23(3): 395 (nutritive value of fish meals)

Maria (*see* Burbot)

Markert, John Richard
J 23(7): 1095 (pigment in salmon skin)

Marking methods, returns and interpretation (*see also* Tagging)
J 23(7): 1043 (re pink salmon ocean distribution & migration)
(11): 1761 (longnose & white suckers, Sixteenmile L., B.C.)

Marlin, blue (*Makaira nigricans*)
CSG 49 (identification)

Marlin, white (*Makaira albicans*)
CSG 49 (identification)

Maskinonge (*Esox masquinongy*) (muskellunge)
J 23(11): 1663 (muscle myogens electrophoregram)

Masu (*Oncorhynchus masu; O. masu ishikawae*) (masu salmon)
J 23(1): 101 (biochemical evidence re *Oncorhynchus* inter-species relationships)

Mathematical treatment
J 23(2): 163 (fitting growth curves to observed data)
(2): 246, (3): 423 (selectivity of gillnets for lake whitefish)
(3): 349 (exploitation in a predator–prey relationship type)
(5): 689 (depensatory process based on hunger concept)
(6): 869, (8): 1209 (of feed & growth factors in fishes)
(9): 1411 (electrical analog model for wind-driven marine currents)
(10): 1495, 1523 (re pike feed consumption)
(10): 1553 (methods of estimating exploited populations)
S 979 (flushing rates estimation from tide height & current data)
994 (abundance & fishing success)
1070 (computer method for calculating Kendall's *tau*)

Mating
J 23(9): 1319 (& premating behaviour of Dungeness crab)

Mathisen, Ole Alfred
J 23(3): 459 (Ozernaya sockeye salmon)

Matter, particulate, in natural waters
J 23(10): 1625 (comparison of estimation methods)

Maturation; maturity
J 23(3): 455 (re size of spottail shiner)
(5): 623 (brook trout in infertile Pennsylvania streams)

(5): 651 (sexual, of Nfld. & Grand Bank American plaice)
(6): 797 (southern Nfld. herring population)
(7): 947 (salmon parr in Nabisipi R., Que.)
(8): 1145 (Atlantic argentine on Scotian Shelf)
B 153: 116 (size & age of, petrale sole)

May, Arthur William
J 23(7): 1083 (deck sampling of catches)
S 1020 (catchability of cod)
1021 (cod otolith ageing)
1052 (cod growth & temperature in Nfld. area)
1059 (cod research catches re depth & temperature)

McCracken, Francis Derwood
J 23(8): 1145 (Atlantic argentine)

McCrimmon, Hugh Ross
J 23(2): 275 (comparative limnology)
(7): 983 (trout response to light)

McKenzie, Russell Alderson
S 1076 (1965 offshore lobster investigations)

McKnight, Ida Marie
J 23(1): 45 (blood of mountain whitefish)

McLachlan, Jack
J 23(3): 357 (dimethyl-β-propiothetin)
S 1044 (dimethyl-β-propiothetin in algae)

McLaren, Ian Alexander
J 23(5): 769 (analysis of ringed seal census)
S 1012 (plants from Ogac Lake)
1013 (zooplankton of Lake Hazen)

McLeese, Donald Wilson
J 23(9): 1325 (incidence of *Gaffkya homari*)

McPhail, John Donald
J 23(1): 141 (the *Coregonus autumnalis* complex)
(5): 767 (technique for obtaining chromosomes from teleost fishes)

Meals, fish (*see* Fishmeals)

Mealworm (*Tenebrio molitor*)
S 1028, 1080 (fatty acids positional distribution in fat triglycerides)

Medcolf, John Carl
J 23(7): 1101 (observations on eels)

Megaptera novaeangliae (*see* Whale, humpback)

Melanogrammus aeglefinus (*see* Haddock)

Mendota, Lake, Wisconsin
J 23(4): 499 (yellow perch activity & distribution under ice)

Menhaden, Atlantic (*Brevoortia tyrannus*)
J 23(3): 395 (protein nutrient quality of fishmeal)

Mercer, Malcolm Clarence
J 23(8): 1257 (*Pyrgopsis lemur* (Cephalopoda; Cranchiidae) from NW Atl.)

Meristic characteristics (*see also* Species, new; *also* Length; Size; Weight; etc.)
J 23(11): 1815 (yellow perch meristic numbers re lake salinity)
S 1061 (salmons of Cape Thompson region, Alaska)

Merluccius bilinearis (*see* Hake, silver)

Merluccius productus (*see* Hake, Pacific)

Mesh (*see* Nets)

Metabolism
J 23(1): 1 (brook trout respiratory function)
(1): 65, (4): 471, (6): 783, (9): 1461 (rainbow trout: effects of activity, etc. on)
(3): 357, (4): 487 (phytoplankton thetin to acrylic acid & dimethyl sulphide)
(6): 869, (8): 1209 (re body weight of fishes: effect of feed & water temperature)
S 1040 (carbohydrate, of marine planktonic algae)

Meteorology (*see also* Wind)
S 1056 (air temperature anomalies off Nfld.)

Micropterus dolomieui (*see* Bass, smallmouth)

Micropterus salmoides (*see* Bass, largemouth)

Microstomus pacificus (*see* Sole, Dover)

Migration (*see also* Distribution; Marking; Movements; Spawning; Tagging)
J 23(1): 109 (vertical, of some demersal Atl. fishes)
(1): 157 (downstream, of brown trout, re temperature & light)
(2): 181 (spawning: swimming speed of sockeye & coho salmon)
(4): 499 (vertical, of yellow perch under ice)
(7): 1043 (oceanic, of fin-marked pink salmon)
(7): 1101 (habits of American eel)
(8): 1135 (vertical, of NE Pac. oceanic shrimps)

S 998 (sockeye salmon swimming dynamics)
1000 (oceanic, of 5 Pac. salmon species)

Milt (*see also* Gonads)
S 1011, 1036 (steelhead & sockeye salmon as enzyme source)

Mineral content (*see also* Composition (chemical and physical))
J 23(8): 1285 (of various phytoplankton species)

Minnow, bluntnose (*Pimephales notatus*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Minnow, mud (*Umbra limi*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Miramichi River, N.B.
J 23(12): 1977 (brook trout & young salmon association factors)

Mitchell, Edward
J 23(12): 1897 (Pleistocene sea otters)
S 1079 (extinct N Pac. marine mammals)

Model
J 23(9): 1411 (electrical analog, for wind-driven currents)

Moisture content
J 23(5): 775 (equilibrium values for fresh & salt Atlantic cod)
(9): 1353 (pink salmon at various life-history stages)

Mollusca (*see* individual names)

Monkfish (*Lophius americanus*) (angler; goosefish)
B 154: 115 (as Nfld. resource)

Moonfish (*see* Opah)

Moore, Barbara Anne
J 23(1): 27 (rancidity in lean fish muscle)
(5): 737 (TBA values from cod muscle)
(9): 1385 (rancidity in cod fillets)

Morphology (*see also* names of organisms, organs and tissues)
J 23(10): 1607 (Atlantic cod digestive tract)
(12): 1845 (freshwater fishes: mouth & body form re feeding ecology)

Morphometry (*see also* Morphology; Species, new records)
J 23(12): 1875 (of 9 Rocky Mt. Trench SE B.C. lakes)

Mortality
J 23(2): 256 (rate of lake whitefish, Georgian Bay)
(10): 1507 (of otter-trawled haddock from fatigue)
B 153: 118 (rates of B.C. petrale sole)
S 982 (re self-regulation of sockeye salmon population abundance)
1053 (mass, of various Nfld. area sea fishes re low temperatures)
1062, 1063, 1064 (B.C. salmons: sockeye; pink; chum)

Morton, Margaret Louise
CHN 23 (superchilled storage of cod)

Mouth
J 23(10): 1607 (Atlantic cod morphology)
(12): 1845 (re feed & body form of 14 freshwater fishes)
(12): 1971 (anatomy re pelagic shrimps feeding habits)

Movements (see also Behaviour; Distribution; Marking; Migration; Tagging)
J 23(4): 499 (yellow perch under ice)
(10): 1475 (cutthroat trout in open water)

Moxostoma erythrurum (*see* Redhorse, golden)

Moxostoma macrolepidotum (*see* Redhorse, northern)

Mud, marine
J 23(11): 1635 (phosphate, nitrate & bacteria in P.E.I. oyster-bearing)

Mugil cephalus (*see* Mullet, striped; *also* Mullet)

Mullet (probably striped mullet)
CCG 7: 33 (latent heat of freezing)
S 980 (brining time before smoking)

Mullet, striped (*Mugil cephalus*) (*see also* Mullet)
S 1009 (occurrence of odd-numbered fatty acids in oil)

Mummichog, freshwater (see Killifish, banded)

Murray, John
J 23(11): 1795 (hypoxanthine in salmon muscle)

Muscle (*see also* Fillets; Myogens; Protein)
J 23(1): 65, (4): 471, (9): 1461 (effect of activity on metabolism, in rainbow trout)
(4): 527 (glycogenolytic enzymes in Atlantic cod)
(5): 673 (free drip & *p*H re chalkiness, in Pacific halibut)
(5): 737, (10): 1587 (iron salts effect on rancidity test)
(6): 921 (nucleotide interference with glycogen determination in red & white, of Atlantic cod)
(7): 1025 (lipids of fresh vs. frozen Atlantic cod)

(12): 1821 (nucleotide degradation re quality of ordinary and red, of swordfish)
(12): 1913 (histopathology of induced inflammation in Pacific oyster)
S 1043 (Atlantic cod red vs. white: post-mortem glycolytic metabolites)
1049 (guanine deaminase of lingcod)
1073 (enzymes of Atlantic herring)

Muskellunge (*see* Maskinonge)

Mussel, Bay (Pacific) (*Mytilus edulis*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)

Mussel, blue (*Mytilus edulis*)
B 154: 127 (as Nfld. resource)

Mussel, horse (*Vosella modiolus*)
B 154: 127 (as possible Nfld. resource)

Mya arenaria (Atlantic: *see* Clam, softshell; Pacific: *see* Clam, mud)

Mylochielus caurinum (*see* Chub, peamouth)

Myogens
J 23(1): 101 (of *Oncorhynchus* re interspecies relationships)
(10): 1599 (of Salmonidae re interrelationships)
(11): 1663 (of muscle of various fish families re relationships)

Myoglobin
B 150: 15 (role in "greening" of albacore & tuna flesh during precooking before canning)

Myosin
J 23(4): 563 (preparation & properties of rainbow trout)

Myoxocephalus octodecemspinosus (*see* Sculpin, longhorn)

Myoxocephalus quadricornis (*see* Sculpin, fourhorn)

Mysis relicta (a malastrocan)
S 1004 (re Canadian Arctic Is. marine-glacial relicts),

Mytilus edulis (*see* Mussel, blue; Mussel, bay)

Myxophryceae
J 23(8): 1285 (dry weight, ash & volume data for *Oscillatoria*)
(11): 1715 (of Lake Ontario surface waters)
S 1040 (enolase activity)

N

Nabisipi River, Que.
J 23(7): 947 (juvenile Atlantic salmon & tagging results)

Nagayama, Fumio
S 1071 (cholesterol glucopyranosiduronate)

Nalewajko, Czeslawa
J 23(8): 1285 (freshwater planktonic algae composition)
(11): 1715 (phytoplankton in Lake Ontario)

Narragansett Bay, Rhode Island
J 23(2): 189, (3): 415 (free-swimming copepod nauplii: descriptions; key; seasonal occurrence; abundance)

Natantia
J 23(8): 1135 (NE Pac. oceanic shrimps depth distribution)

Nauplii
J 23(2): 189, (3): 415 (of free-swimming copepods)

Neal, Wanda Eloise
J 23(1): 27 (rancidity in lean fish muscle)
(5): 737 (TBA values from Atlantic cod muscle)
(9): 1385 (rancidity in Atlantic cod fillets)

Neave, Ferris
S 1063 (pink salmon in B.C.)
1064 (chum salmon in B.C.)
1065 (deacylation of triglycerides)

Neave, Nancy Mae
J 23(10): 1617 (buoyancy in salmon)

Neilsen, John Rickart
J 23(9): 1319 (mating behavior of Dungeness crab)

Nematoda
S 1001 (in Risso dolphin stomach)

Net, gill (*see* Selectivity of fishing gear)

Net, trap
S 1084 (harp seals on N shore of St. Lawrence R.)

Newfoundland region (*see also* Grand Bank; Labrador; North Harbour River; *also* International Commission for the Northwest Atlantic Fisheries)
B 154 (scientific & statistical aspects of marine resources)
CJG 13 (groundfish & squid surveys, catches, gear catches, etc.)
S 1007, 1085: 8, 1105 (Atlantic salmon & transplanted pink salmon)
1022 (cod fishery trends)
1051–1060 (cod & haddock biological factors)
1056 (sea & air temperature anomalies)
1069 (two further records of American shad)

Nickerson, Richard Barret
J 23(5): 729 (size-class of king crabs)

Nicola Lake, B.C.
J 23(8): 1259 (seasonal & diel changes in adult kokanee feed)

Nicotinamide
B 150: 15 (as inhibitor of albacore & tuna flesh "greening")

Nicotinic acid (see Vitamin B group)

Nigrelli, Ross F.
S 1002 (studies on virus diseases of fishes)

Nitrogen compounds of tissues (*see also* Acids, amino; Trimethylamine; *also* other classes of nitrogen compounds)
J 23(11): 1653 (American crayfish meat)

Nitrite
B 150: 15 (as inhibitor of albacore & tuna flesh "greening")

Noel, Thomas Corbin
J 23(5): 775 (equilibrium values of cod)

North Harbour River, Nfld.
J 23(6): 939 (scale characteristics of transplanted B.C. pink salmon)
S 1007 (spawning returns of transplanted B.C. pink salmon)

Northcote, Thomas Gordon
J 23(8): 1259 (food of kokanee)
(11): 1761 (sucker life histories)

Northumberland Channel, B.C.
S 979 (tidal flushing rates re pulpmill effluent dispersal)

Northwest Territories, Canada (N.W.T.) (*see* Arctic, Canadian, *also* names of individual localities)

Nota, Dirk Johannes Gregorius
J 23(8): 1197 (sea-floor conditions)

Notemigonus crysoleucas (*see* Shiner, golden)

Notropis heterodon (*see* Shiner, blackchin)

Notropis hudsonius (*see* Shiner, spottail)

Nucleosides and nucleotides (*see* also Hypoxanthine)
J 23(6): 921 (interference with Atlantic cod muscle glycogen determination)
(12): 1821 (nucleotide degradation re swordfish ordinary & red muscle quality
S 1011, 1036 (nucleoside phosphates synthesis by salmon-milt enzyme)
1036 (& enzyme systems in fish)
1041 (*Daphnia magna* encysted embryos nucleotides)

Nutrition value (*see also* Composition (chemical and physical); Feed)
J 23(3): 395 (of protein in fishmeals)
(11): 1653 (of American crayfish meat)

O

Obituaries
J 23(5): 779 (John Richardson Dymond)
(11): 1790 (W. F. Thompson)

Observation, underwater
J 23(1): 153 (of fish behaviour towards otter trawl)
(8): 1197 (photographic, of sea bottom)

Ocean (*see* name of ocean, *also* Oceannography)

Oceanography, B.C. coast (*see also* Georgia, Strait of; Juan de Fuca, Strait of; Oceanography, north and northeast Pacific)
CNS 14, 19 (groundfish landings by areas, & utilizations, 1964, 1965)
S 979 (tidal flushing rates re pulpmill effluent into channels near Nanaimo)
1032 (time series of variables)

Oceanography, Canadian arctic and subarctic
J 22(1): 225 (Fury and Hecla Strait currents)
(4): 539 (re spring primary productivity in E subarctic)

Oceanography, Canadian coastal Atlantic (*see also* Fundy, Bay of; St. Lawrence, Gulf of)
J 23(5): 651 (temperature re depth off Nfld.)
(8): 1197 (sea floor geomorphology off Magdalen Is.)
(11): 1635 (nutritional cycles in P.E.I. oyster area)
B 154: 23 (re Nfld. fishery resources)
155: 8 (synopsis of)
S 1023, 1024, 1026 (in ICNAF waters)
1026 (1964 another cold seawater year in ICNAF areas)
1051–1053, 1055–1060 (temperature re Nfld. areas cod & haddock)
1056 (sea & air temperature anomalies off Nfld.)
1109 (surface circulation on Continental Shelf, Nfld. to Florida)

Oceanography, general
S 1014 (possible estimation of oceanic thermocline depth from satellite data)

Oceanography, north and northeast Pacific (*see also* Oceanography, B.C. coast)
S 977 (wind speed re summer isothermal surface layer)
1032, 1033 (time series of variables at weathership)
1038 (re 1964 Canadian INPFC salmons research)

Octopus (Pacific)
CSN 14 (B.C. landings by areas, 1965)

Odense, Paul Holger
J 23(9): 1465 (salinity tolerance levels)
(10): 1607 (digestive tract of cod)
(12): 1841 (epithelial border of cod)
S 1073 (enzymes in herring)

Odours (*see also* Quality of fishery products)
J 23(3): 357, (4): 487 (marine phytoplankton thetin as precursor of dimethyl sulphide odour in fish products)
CNG 25 (dimethyl sulphide re "blackberry" condition in Atlantic cod)
S 1034 (dimethyl sulphide re "blackberry" condition in Atlantic cod)

Oesophagus
J 23(10): 1607 (Atlantic cod morphology)

Ogac Lake, N.W.T.
S 1012 (list of vascular plants from around)

Ogrefish (*see* Fangtooth)

Oikawa, Toyoko Gene
S 996 (synthesis & properties of 2′, 5′-dideoxyadenosylcobalamin & 5′-deoxythymidylcobalamin)
1041 (nucleotides in *Daphnia* embryos)

Oilfish (*Ruvettus pretiosus*)
CSG 49 (identification)

Oils and fats, marine animal(*see also* Acids, fatty; Antioxidants; Lipids)
J 23(1): 21, 155 (Atlantic cod liver treatments effect on liver oil free fatty acids)
(5): 681 (pilot plant fractionation of methyl esters from Pacific herring)
(6): 917 (free, in canned sockeye salmon: binding effect of prior treatment of fish)
(12): 1835 (digestion of by Atlantic cod)
S 972 (fatty acids types in various Atl.)
1080 (fatty acids positional distribution in depot fat triglycerides)

Oil, vegetable
S 1074 (rapeseed monoethylenic fatty acids)

Oils, liver (*see* Oils and fats, marine animal)

Oncorhynchus (species in general) (*see* Salmons Pacific, inclusive)

Oncorhynchus gorbuscha (*see* Salmon, pink)

Oncorhynchus keta (*see* Salmon, chum)

Oncorhynchus kisutch (*see* Salmon, coho)

Oncorhynchus masu (*see* Masu)

Oncorhynchus nerka (*see* Salmon, socheye)

Oncorhynchus tshawytscha (*see* Salmon, chinook)

Ontario, Lake (*see also* Great Lakes)
J 23(11): 1715 (biological composition of surface phytoplankton)

Opah (*Lampris regius*) (Jerusalem haddock; moonfish)
CSG 49 (identification)

Ophiodon elongatus (*see* Lingcod)

Opinicon, Lake, Ont.
J 23(12): 1845 (fishes mouth & body form re feeding ecology)

Orconectes limosus (*see* Crayfish, American)

Oregon, U.S.A.
J 23(11): 1673 (sea stars bathymetric distribution)

Osmerus mordax (*see* Smelt, American)

Ossiander, Frank James
J 23(5): 729 (size-class of king crabs)

Otoliths
J 23(3): 463 (re Bay of Fundy capelin age)
(8): 1151 (formation in Atlantic argentine)
S 997 (Atlantic cod: international exchange for age determination comparisons)
1021 (validity of age from, for Atlantic cod)

Otter, sea (*Enhydra lutris*)
J 23(12): 1897 (re Pleistocene fossil ancestors)

Otter trawl (*see* Trawl, otter)

Outram, Donald Noel
CNG 74 (1965 herring spawn in B.C.)

Ova (*see* Eggs, fish)

Ovary (*see* Gonads)

Oxidation
CVG 36 (control of B.C. herring meals by antioxidants)

Oxygen dissociation (*see also* Respiration)
J 23(1): 1, (8): 1187 (of brook trout & Atlantic salmon blood)

Oxygen, dissolved (*see also* Limnology; Oceanography)
J 23(8): 1121 (re temperature in trouts embryo development)

Oyster, Atlantic (*Crassostrea virginica*)
J 23(4): 595 (in vitro cultivation of cardiac tissue cells)
(11): 1635 (nutrient & energy cycles in Malpeque Bay, P.E.I.)

CJG 13: 48 (growth in Nfld. barachois pond)
CSG 48 (further progress in rehabilitating Maritimes stocks)

Oyster, Pacific (*Crassostrea gigas*)
J 23(8): 1265 (occasional toxicity in Strait of Georgia)
(12): 1913 (turpentine-induced inflammation histopathology
S 1097 (brief description; biology; B.C. culture)

P

Pacific Ocean, northeastern (*see also* Oceanography)
J 23(1): 85 (stomach content of salmons & steelhead trout)
(2): 305, 309, 313 (new fish records)
(4): 539 (spring phytoplankton bloom in subarctic)
(6): 825 (variability of conditions between Cape Flattery & ocean weathership station)
(7): 1043 (fin-marked pink salmon migration & distribution)
(8): 1135 (oceanic shrimps depth distribution off Oregon)
CNS 15, 20, 21, 22, 23 (salmonids stomach contents, 1956–64)
S 973 (coho salmon life history, stocks, distribution, etc.)
974 (5 salmon species distribution & mingling of E & W stocks)

Packaging
B 151: 25 (freshwater fish specialty products)

Pagophilus groenlandicus (*see* Seal, harp)

Palaeontology
J 23(12): 1897 (of modern sea otter)

Palatability (*see* Quality of fishery products)

Paloheimo, Jyri Erkki
J 23(6): 869 (food & growth of fishes)
(8): 1209 (food & growth of fishes)
S 994 (abundance & fishing success)

Pancreas
J 23(10): 1607 (Atlantic cod morphology)

Pandalus borealis (*see* Shrimp, pink)

Pandalus montagui (*see* Shrimp, striped pink)

Pantothenic acid (*see* Vitamin B group)

Paralithodes camtschatica (*see* Crab, king)

Parasites and parasitism
J 23(4): 521 (copepod *Sphyrion lumpi* reproduction)
(12): 1965 (flagellate *Cryptobia salmositica* in sockeye salmon)
CCG 7: 9 (*Triaenophorus crassus* re whitefish)
S 981 (trematode fluke larvae infesting limpet)
1010 (*Parabomolochus* copepod on seaperch gills)

Park, Tai Soo
J 23(6): 805 (new species of *Bradyidius*)

Parker, Robert Ray
J 23(9): 1353 (composition of young pink salmon)

Parsons, Timothy Richard
J 23(4): 539 (spring phytoplankton bloom)
S 989 (growth rate of phytoplankton)

Parophrys vetulus (*see* Sole, lemon (Pacific))

Pasiphaea pacifica (*see* Shrimps, oceanic)

Patella vulgata (*see* Limpet)

Pathological conditions (*see* Disease; Inflammation)

Pauley, Gilbert Buckhannan
J 23(12): 1913 (inflammation in the Pacific oyster)

Pearcy, William Gordon
J 23(8): 1135 (oceanic shrimps)
(12): 1971 (food of pelagic shrimps)

Pearson, Roger Eugene
J 23(5): 747 (scales of pink salmon)

Peden, Alex Edward
J 23(2): 313 (red gunnel & slimy snailfish)
(8): 1277 (rare marine fishes)

Peer, Donald Lloyd
J 23(3): 455 (maturity of spottail shiner)

Pelage
J 23(4): 607 (foetal & postpartum of harbour seals)

Pennsylvania, U.S.A.
J 23(5): 623 (maturation & fecundity of brook trout in infertile streams)

Perca flavescens (*see* Perch, yellow)

Perception (*see also* Light, reactions to)
J 23(9): 1331 (of surface ripples by topminnow lateral line organs)

Perch (Pacific)
CSN 14, 19 (B.C. landings by areas, 1964, 1965)

Perch, log (*Percina caprodes*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Perch, Pacific Ocean (*see* Rockfish, longjaw)

Perch, yellow (*Perca flavescens*)
J 23(1): 15 (total annual growth dependence on temperature)
(1): 149 (alkaline phosphatase in scales)
(4): 499 (diel activity & vertical distribution under ice)
(11): 1807 (pugheadedness abnormality, Heming L., Man.)
(11): 1815 (meristic numbers in Man. saline lakes)
(12): 1845 (mouth & body form re feeding ecology)
CCG 7: 16 (protein electropherograms)

Percina caprodes (*see* Perch, log)

Peterson, Alvin Edward
S 974 (offshore distribution of salmon)

Petromyzon marinus (*see* Lamprey, sea)

*p*H
J 23(5): 673 (of flesh & free drip re Pacific halibut flesh chalkiness)
(7): 1077 (of thawed Atlantic cod fillets)

Phoca hispada (*see* Seal, ringed)

Phoca vitulina (*see* Seal, harbour (Atlantic))

Phoca vitulina largha (*see* Seal, harbour (western Pacific))

Phoca vitulina richardi (*see* Seal, harbour (eastern Pacific))

Pholis schultzi (*see* Gunnel, red)

Phosphatase (see Enzymes)

Phosphates
J 23(1): 65 (rainbow trout activity effect on metabolism of)

Phospholipids
J 23(2): 207 (isotope-labelled for testing lecithinase activity)
(7): 1025 (of fresh vs. frozen Atlantic cod muscle)
S 986 (simplified preparation of glyceryl phosphoryl choline)
1045 (polyunsaturation re iodine value of various marine animal oils)

Phosphorus compounds (*see also* Nucleosides; Phosphates; Phospholipids)
J 23(11): 1653 (of American crayfish meat)
S 1036 (in fish)

Photography, underwater (see also Observation, underwater)
J 23(8): 1271 (of fish specimens in aquarium)
S 1087 (of reaction of Atl. fishes to otter trawl)

Photoperiods (*see* Light, reactions to)

Phytosynthesis (*see also* Phytoplankton)
J 23(4): 539 (at critical depth in E subarctic Pac.)

Physeter catodon (*see* Whale, sperm)
B 154: 138 (as Nfld. resource)

Phytoplankton
J 23(3): 357 (thetin content as precursor of dimethyl sulphide odour in fish products)
(4): 539 (spring bloom advent in E subarctic Pac.)
(8): 1285 (dry weight, ash & volume data for various species)
(11): 1715 (biological composition of, in Lake Ontario surface waters)
B 122 (revised ed.) (measuring productivity of marine)
S 1040 (enolase activity of marine algal)
1044 (*Syracosphaera carteri* content of a thetin)

Pickerel (*see* Pike, northern; *also* Walleye)

Pickerel, yellow (*see* Walleye)

Pig (*see* Pork)

Pigments; Pigmentation
J 23(6): 921 (Atlantic cod red vs. white muscle glycogen)
(7): 1025 (Atlantic cod red vs. white muscle lipids)
(7): 1095 (of coho salmon belly skin)
(12): 1981 (a bocaccio xanthochroic colour variant)
B 150 ("greening" of albacore & tuna flesh during precooking before canning)

Pike, Gordon Chesley
S 1001 (first B.C. record of *Grampus griseus*

Pike, northern (*Esox lucius*) (pickerel; jackfish)
J 23(1): 149 (alkaline phosphatase in scales)
(10): 1495, 1523 (feed consumption re growth & maintenance)
(11): 1663 (muscle myogens & blood hemoglobins electropherograms)
(11): 1807 (pugheadedness abnormality, Heming L., Man.)
(12): 1845 (mouth & body form re feeding ecology)
(12): 1969 (second record of accessory fin)
CCG 7: 9 (control re whitefish infestation by *Triaenophorus*)
7: 16 (protein electropherogram)
7: 33 (freezing rate; latent heat of freezing)

S 980 (brining time before smoking)
1015 (Great Slave L. sport fishing)
1081 (sweet-cured smoked sliced products; recipes)

Pike, yellow (*see* Walleye)

Pilchard (*Sardinops sagax*)
S 1080 (fatty acids positional distribution in oil triglycerides)

Pilot plant (*see* Plant, pilot)

Pimephalus notatus (*see* Minnow, bluntnose)

Pinhorn, Allenby Thomas
S 1019 (age & growth in Nfld. inshore cod fishery)
1052 (cod growth & temperature in Nfld. area)

Pitt, Thomas Kenton
J 23(5): 651 (spawning of American plaice)
(7): 1099 (development of anal fin of capelin)

Placopecten magellanicus (*see* Scallop, giant)

Plaice, American (*Hippoglossoides platessoides*)
J 23(1): 109 (vertical migrations)
(5): 651 (sexual maturity & spawning, Nfld. & Grand Banks)
B 154: 4, 81, 154 (as Nfld. resource)
CJG 13: 24 (Nfld. spawning & catches)
S 1023, 1024 (ICNAF Canadian research reports)
1087 (behaviour toward otter trawl, observed photographically)

Plankton (*see also* Phytoplankton, Zooplankton)
J 23(10): 1625 (efficiency of methods for determining)
(12): 1875 (of 9 Rocky Mt. Trench B.C. lakes)

Plant, pilot
J 23(5): 681 (for Pacific herring oil methyl esters fractionation)

Plants (*see* Flora)

Plasma, blood
J 23(1): 65, (4): 471 (6): 783 (activity effect on metabolism in rainbow trout)
(1): 101 (proteins of *Oncorhynchus* re inter-species relationships)
(9): 1439 (volume in salmonids blood)

Platichthys stellatus (*see* Flounder, starry)

Pletcher, Ferdinand Tony
J 23(2): 309 (new B.C. fishes)
(8): 1271 (photographing fish at sea)

Poisons (*see* Pollution; Toxicants)

Pollachius virens (*see* Pollock)

Pollock (*Pollachius virens*) (pollack)
J 23(10): 1587 (lipid oxidation test)
B 154: 109 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)

Pollock, walleye (*see* Whiting (Pacific))

Pollution
J 23(6): 813 (pulpmill, re young Atlantic salmon)
MSP 9 (collected copies of studies related to FRB work, 1902–66)
S 979 (pulpmill, re tidal flushing rates in channels near Nanaimo, B.C.)
999 (Cu & Zn mine effluent re Atlantic salmon)
1007 1085 (mining & insecticide, re Atlantic salmon & trout)
1066 (pulpmill sulphite wastes in partially enclosed marine system near Prince Rupert, B.C.)

Polychaeta
S 1067 (new B.C. records & distribution extensions)

Pomoxis nigromaculatus (*see* Crappie, black)

Pontoporeia affinis (a malastrocan)
S 1004 (re Canadian Arctic Islands marine-glacial relicts)

"Pop-eye" (*see* Eye)

Populations (*see also* Composition (biological))
J 23(2): 221 (dynamics & exploitation of Georgian Bay lake whitefish)
(3): 365 (life history variations in steelhead trout)
(5): 623 (brook trout in infertile Pennsylvania streams)
(5): 729 (fishery effect on size-class structure, king crab)
(5): 769 (aerial census for ringed seal)
(6): 797 (biological characteristics of S Nfld. herring)
(10): 1553 (mathematical treatment of estimating exploited)
(11): 1761 (estimates of longnose & white suckers, Sixteenmile L., B.C.)
B 152 (dynamics of B.C. brill)
S 982 (self-regulating mechanism for abundance of sockeye salmon)
994 (re abundance & fishing success)
1025 (dynamics re ICNAF area)

Porbeagle (*Lamna nasus*)
B 154: 112 (as Nfld. resource)
CSG 47 (identification)

Pork (*see also* Sausage)
S 1028, 1080 (fatty acids positional distribution in salt pork fat triglycerides)

Porpoise Harbour, B.C.
S 1066 (pulpmill sulphite pollution in, & vicinity)

Porpoises
S 1079 (faunal succession of N Pac. extinct)

Post, George
J 23(10): 1487 (response of trout to antigens)
(12): 1957 (rainbow trout serum)

Poultry feed (*see* Feedstuff)

Pout, ocean (*Macrozoarces americanus*)
J 23(3): 341 (swimming endurance re speed)

Powell, Guy Charles
J 23(5): 729 (size-class of king crabs)

Power, Geoffrey
J 23(7): 947 (Nabisipi R. salmon parr)

Power, Henry Edwin
J 23(1): 21 (free fatty acids in cod oil)
(1): 155 (free fatty acids in cod livers)
CHN 23 (superchilled storage of cod)

Prakash, Anand
J 23(8): 1265 (*Gonyaulax acatenella*)

Predation (*see also* Feed)
J 23(2): 241 (sea lamprey on lake whitefish, Georgian Bay, Ont.)
(3): 349 (exploitation in predator–prey relationship)
S 1007, 1085 (on Atlantic salmon, & control)
1025 (control, re feed & competition, ICNAF area)

Preservatives and preservative treatments (*see also* Antibiotics; Antioxidants; Freezing; Rancidity; Refrigeration)
J 23(1): 155 (Atlantic cod livers by irradiation)
(4): 601 (of Red Sea sardines by gamma irradiation)
(5): 701 (partial freezing for Pac. groundfish)
S 1031 (antibiotics for fish products; residues, regulations)

Prey (*see* Feed; Predation)

Primary productivity (*see* Productivity)

Prince Edward Island
J 23(11): 1635 (Malpeque Bay oyster farming conditions)
S 1016 (snake fauna)

Prionace glauca (*see* Shark, blue)

Processing (*see* individual types of processing; *also* Preservatives)

Productivity
J 23(4): 539 (primary, in E subarctic Pac. Ocean)
(11): 1727 (biological, of waters)
(12): 1875 (rank of 9 Rocky Mt. Trench SE B.C. lakes)
B 122 (revised ed.) (measuring, of marine phytoplankton)

Products (*see* individual types of products; *also* under names of certain fishes)

Pro-oxidants (*see also* Antioxidants; Rancidity)
J 23(1): 27, (9): 1385 (effect of various on Atlantic cod muscle rancidity)

Prosopium cylindraceum (*see* Whitefish, round)

Prosopium williamsoni (*see* Whitefish, mountain)

Protein (*see also* Electropherograms; Muscle; Plasma)
J 23(3): 395 (nutrient value of fishmeals)
(7): 975 (effect of starvation & refeeding Atlantic cod on plasma protein)
(9): 1353 (content of pink salmon at various life-history stages)
(12): 1957 (of rainbow trout serum and antibodies)
S 1040 (content of various marine planktonic algae)

Protothaca staminea (*see* Clam, littleneck)

Psettichthys melanostictus (*see* Sole, sand)

Pseudomonas bacteria
J 23(9): 1451 (in lobster)

Pseudopleuronectes americanus (*see* Flounder, winter)

Pteropoda
J 23(1): 85 (*Limacina* in feed of NE Pac. Ocean salmons & steelhead trout)
(4): 487 (*L. helicina* re dimethyl sulphide production in Atlantic cod)
CHS 15, 20, 21, 22, 23 (*Limacina* in NE Pac. Ocean salmonids stomachs)
CHN 25 (*L. helicina* re "blackberry" condition in Atlantic cod)
S 1034 (*L. helicina* re "blackberry" condition in Atlantic cod)

Publications and reports, Fisheries Research Board
J 23(12): 1983 (list of 1966 and some 1965)
R 1964 (list of 1964 and some 1963)

Puget Sound, Washington
J 23(7): 1043 (oceanic distribution & migration of pink salmon fin-marked in)

Pulpmill effluent toxicants (*see* Pollution)

Pump
S 1006 (air-lift, for unloading fish from hold)

Pumpkinseed (*Lepomis gibbosus*) (pumpkinseed sunfish)
J 23(11): 1663 (muscle myogens & blood hemoglobins electropherograms)
(12): 1845 (mouth & body form re feeding ecology)
CCG 7: 16 (protein electropherogram; also of hybrid with bluegill)

Pyrgopsis lemur (*see* Squids)

Pyruvate
J 23(6): 783 (changes in exercised rainbow trout)

Q

Quality of fishery products (*see also* types of processing and products)
J 23(3): 395 (protein nutrient value of fishmeals)
(7): 1063 (taste panel tests of Atlantic cod single & double-frozen fillets)
(11): 1795 (muscle hypoxanthine as test of, in Atlantic salmon)
(12): 1821 (re nucleotide degradation in swordfish muscle)

Quigley, James Joseph
S 1105 (Pac. salmon in Atl.)

R

Rabbit
S 1028, 1080 (fatty acids positional distribution in mesenteric fat triglycerides)

Radiation (*see* Illumination; Irradiation; Isotopes; Light, reactions to)

Radioactivity (*see* Irradiation; Isotopes)

Raja laevis (*see* Skate, barndoor)

Raja ocellata (*see* Skate, winter)

Raja radiata (*see* Skate, thorny)

Raja senta (*see* Skate, smooth)

Raja spinacauda (*see* Skate, spinytail)

Rana pipiens (*see* Frog)

Rancidity, oxidative (*see also* Antioxidants)
J 23(1): 27 (in Atlantic cod muscle: effects of added amino acids, etc.)
(5): 737, (10): 1587 (iron salts effect on thiobarbituric acid test)
(9): 1385 (in frozen stored Atlantic cod fillets)

Randall, David John
S 978 (dorsal aortic pressures in trout)

Range extensions (*see* Species, new records)

Rapeseed oil
S 1074 (monoethylenic fatty acids)

Rat, Albino
S 1028, 1080 (fatty acids positional distribution in subcutaneous & intestinal fat glycerides)

Ratfish (*Hydrolagus colliei*)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by months, 1964, 1965)

Recipes
S 1081 (sweet-cured smoked sliced products from freshwater fishes)

Records, new (*see* Species, new records)

Recruitment
B 153: 94, 130 (B.C. petrale sole stocks)
S 1025 (re ICNAF area fish stocks)

Rectum
J 23(12): 1841 (epithelial border histology in Atlantic cod)

"Red mouth" disease
J 23(10): 1487 (rainbow trout, & antigen)

"Red water"
J 23(8): 1265 (re Strait of Georgia shellfish toxicity)

Redfish (*Sebastes marinus*)
J 23(1): 101 (vertical migrations in NW Atl. Ocean)
(3): 341 (swimming endurance re speed & temperature)
(4): 521 (reproduction of parasitic copepod *Sphyrion lumpi*)
(7): 1083 (deck sampling of research vessel catches)
(10): 1621 (feeding & growth in captivity)
B 154: 3, 69, 154 (as Nfld. resource)
CJG 13: 29 (Nfld. surveys, landings; length distributions)
S 1023, 1024, 1025, 1089 (ICNAF Canadian research reports)
1100 (brief description, life history, etc.)

Redhorse, golden (*Moxostoma erythrurum*)
CCG 7: 16 (protein electropherogram)

Redhorse, northern (*Moxostoma macrolepidotum*)
CCG 7: 16 (protein electropherogram)

Refrigerated sea water (*see* Sea water, refrigerated)

Refrigeration (*see also* Freezing; Sea water, refrigerated)
J 23(9): 1385 (oxidative rancidity in Atlantic cod fillets)
CHN 23 (holding Atlantic cod partially frozen between 30 & 25 F)
S 1027 (effect on length & weight of Atlantic herring)

Regier, Henry Abraham
J 23(2): 221 (lake whitefish)
(3): 423 (selectivity of gill nets)

Regulation (see Management)

Rehabilitation
CSG 48 (Maritimes oyster stocks)

Reinhardtius hippoglossoides (*see* Halibut, Greenland)

Renfro, William Charles
J 23(12): 1971 (food of pelagic shrimps)

Reproduction (*see also* Eggs, fish; Mating; Spawning)
J 23(4): 521 (*Sphryion lumpi* redfish copepod parasite)
(5): 689 (re depensatory process based on sockeye salmon hunger concept)
(5): 757 (rates of harp seal)

Resources
B 154 (marine, of Nfld.)

Respiration, and metabolism of
J 23(1): 1 (re blood of brook trout acclimated to seasonal temperature)
(6): 783 (rainbow trout, after exercise)
(9): 1291 (*Euphausia pacifica*)
S 998 (re sockeye salmon swimming dynamics)

Retina (*see* Eye)

Rhinichthys atratulus (*see* Dace, blacknose)

Rhinichthys cataractae (*see* Dace, longnose)

Rhinichthys evermanni (*see* Dace, umpqua)

Rhodymenia palmata (*see* Dulse)

Riboflavin (*see* Vitamin B group)

Ribonucleic acid (*see* Acids, nucleic)

Ricker, William Edwin
S 1062 (sockeye salmon in B.C.)

Rigor (*see* Muscle)

Rimicola muscarum (*see* Clingfish, kelp)

Roach, Stewart Williard
J 23(5): 701 (fish preservation by partial freezing)
S 1006 (methods for unloading fish)

Roberts, Eve
J 23(1): 101 (*Oncorhynchus* muscle myogens)
(6): 929 (micro starch gel electrophoresis)
(10): 1599 (muscle myogen patterns)
(11): 1663 (comparative electropherograms)

Robson, Douglas Sherman
J 23(3): 423 (selectivity of gill nets)

Roccus chrysops (*see* Bass, white)

Rockfish, canary (*Sebastodes pinniger*)
J 23(9): 1469 (range extension in N Pac.)

Rockfish, copper (*Sebastodes caurinus*)
J 23(9): 1455 (northern Pac. range extension)

Rockfish, greenstriped (*Sebastodes elongatus*)
J 23(9): 1455 (northern Pac. range extension)

Rockfish, longjaw (*Sebastodes alutus*) (Pacific Ocean perch)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 19 (B.C. landings by areas; used for reduction, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Rockfish, pigmy (*Sebastodes wilsoni*)
J 23(12): 1967 (B.C. northern range extension; distinction from *S. emphaeus*)

Rockfish, Puget Sound (*Sebastodes emphaeus*)
J 23(12): 1967 (distinction from *S. wilsoni*)

Rockfish, shortbelly (*Sebastodes jordani*)
J 23(2): 309 (first B.C. coastal record)

Rockfish, yellowtail (*Sebastodes flavidus*)
J 23(9): 1469 (range extension in N Pac.)

Rockfishes (general Pacific)
CNG 73 (in Hecate Strait exploratory fishing)
S 1093 (brief description; life history; B.C. fishery)

Rockweeds
B 154: 145 (*Fucus* & *Ascophyllum* as Nfld. resources)

Ronald, Alexander Pollock
J 23(6): 929 (micro starch gel electrophoresis)

Ronquil, northern (*Ronquilus jordani*)
J 23(5): 767 (simple technique for obtaining chromosomes)

Ronquilus jordani (*see* Ronquil, northern)

Roushdy, H. M.
J 23(4): 601 (preservation by irradiation)

Roy, Joan Elaine
S 1011 (phosphorylation in salmon milts)
1049 (guanine deaminase in lingcod)

Royer, Leroy Merne
J 23(5): 723 (determination of toxaphene)

Ruff, black (*Centrolophus niger*) (blackfish)
J 23(8): 1161 (first Canadian Atl. record: description, distribution, morphometry)

Ruggieri, G. D.
S 1002 (studies on virus diseases of fishes)

Ruvettus pretiosus (*see* Oilfish)

S

Sablefish (*Anoplopoma fimbria*) (black cod)
J 23(1): 153 (underwater observation in off-bottom trawl)
(5): 701 (partial freezing for preservation)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14 (B.C. landings by areas, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)
S 1088 (brief description of biology & B.C. fishery)

Sailfish (*Istiophorus albicans*)

Saito, Akira
J 23(6): 915 (vitamins B in dulse)
S 1071 (cholesterol glucopyranosiduronate)
1072 (sterols in Irish moss)

Salinity (reactions to)
J 23(2): 293 (re aggregations of chum salmon fry)
(3): 319 (re Pacific cod embryonic development)
(9): 1465 (tolerance levels of Atlantic cod to low)
(11): 1815 (re meristic numbers of fishes in saline lakes)

Salinity of marine waters (*see* Oceanography)

Salmo clarki (*see* Trout, cutthroat)

Salmo clarki clarki (*see* Trout, Yellowstone cutthroat)

Salmo gairdneri (*see* Trout, steelhead; Trout, rainbow)

Salmo salar (*see* Salmon, Atlantic)

Salmo salar sebago (*see* Salmon, Atlantic landlocked)

Salmo trutta (*see* Trout, brown)

Salmon, Atlantic (*Salmo salar*)
J 23(6): 813 (reducing pulpmill toxicants to young)
(7): 947 (biology & tagging of parr in Nabisipi R., Que.)
(7): 1007 (responses of young to light)
(8): 1187 (effect of seasonal temperature acclimation on blood functions)
(10): 1575 (hemolysis effect on hemoglobin oxygen affinity)
(10): 1617 (parr adjustment of buoyancy re water velocity)
(11): 1795 (hypoxanthine in muscle of chill-stored)
(11): 1803 (estuarine spawning, P.E.I.)
(12): 1977 (distribution in association with brook trout)
B 154: 99 (as Nfld. resource)
S 999 (sublethal Cu–Zn pollution effect on young)
1007 (1964–65 report on investigation & management)
1035, 1082 (W Greenland fishery)
1083 (age, etc. from scales)
1085 (investigation & management)
1101 (description, life history, etc.)

Salmon, Atlantic landlocked (*Salmo salar sebago*)
J 23(10): 1575, 1581 (hemolysis effect on hemoglobin oxygen affinity)

Salmon, chinook (*Oncorhynchus tshawytscha*) (*see also* Salmons, Pacific, inclusive)
S 1080 (fatty acids positional distribution in triglycerides)

Salmon, chum (*Oncorhynchus keta*) (*see also* Salmons, Pacific, inclusive)
J 23(1): 85 (stomach contents in NE Pac. Ocean)
(2): 293 (factors affecting fry schooling)
(9): 1403 (times of scale annulus formation, Gulf of Alaska)
CNS 16, 27 (age & length composition of 1964 & 1965 B.C. catches)
S 1064 (life history review of B.C.)

Salmon, coho (*Oncorhynchus kisutch*) (silver salmon) (*see also* Salmons, Pacific, inclusive)
J 23(1): 85 (stomach contents in NE Pac. Ocean)

(1): 153 (underwater observations in off-bottom trawl)
(2): 181 (swimming speed on spawning migration)
(7): 1095 (pigments in belly skin)
(9): 1439 (blood volume determination)
S 973 (life history, stocks, distribution, etc. in NE Pac. Ocean)

Salmon, masu (*see* Masu)

Salmon, pink (*Oncorhynchus gorbuscha*) (*see also* Salmons, Pacific, inclusive)
J 23(1): 85 (stomach contents in NE Pac. Ocean)
(5): 747 (scale formation re age determination)
(6): 939 (scale characteristics of B.C. to Nfld. transplants)
(7): 1043 (ocean migration & distribution of fin-marked)
(9): 1353 (chemical composition changes during early sea life)
(9): 1403 (times of scale annulus formation, Gulf of Alaska)
B 154: 102 (as possible Nfld. native resource)
CNS 16, 27 (age & length composition of 1964 & 1965 B.C. catches)
S 1007, 1085, 1105 (results of transplantation to North Harbour R., Nfld.)
1063 (life history review of B.C.)

Salmon, red (*see* Salmon, sockeye)

Salmon, silver (*see* Salmon, coho)

Salmon, sockeye (biology) (*Oncorhynchus nerka*) (red salmon) (*see also* Salmons, Pacific, inclusive)
J 23(1): 85 (stomach contents in NE Pac. Ocean)
(2): 181 (swimming speed on spawning migration)
(3): 459 (scale characteristics of Asian vs. Bristol Bay)
(5): 689 (depensatory process based on hunger concept)
(9): 1403 (times of scale annulus formation, Gulf of Alaska)
(9): 1439 (blood volume determination)
(12): 1965 (first record of *Cryptobia salmositica* flagellate in)
B 154: 102 (as possible Nfld. native resource)
CNS 16, 27 (age & length composition of 1964 & 1965 B.C. catches)
S 982 (population abundance self-regulation mechanisms)
998 (swimming energetics)
1062 (life history review of B.C.)

Salmon, sockeye (products)
J 23(6): 917 (effect of partial freezing, on oil of subsequently canned)
S 1011 (milt enzyme for nucleoside phosphate synthesis)

Salmon, steelhead (*see* Trout, steelhead)

Salmonidae (*see also* individual species)
J 23(1): 101, (6): 929, (10): 1599 (myogen & hemoglobin characteristics)
(10): 1537 (developmental rate & vertebral number)

Salmons, Pacific, inclusive (*see also* individual species; *also* Kokanee; Masu; Trout, steelhead)
J 23(1): 101 (biochemical evidence re interspecies relationships)
(7): 1089 (portable press for making scale impressions)
CNS 15, 20, 21, 22, 23 (stomach contents, NE Pac. Ocean, 1956–64)
S 974 (catches & relative abundance; biological data; in NE Pac. Ocean)
1000 (sea life; E–W Pac. migration; feed; research gear)
1038 (INPFC 1964 research on high seas fishing & tagging)
1061 (as a resource of Cape Thompson region, Alaska)
1092 (brief descriptions; life history)

Salting; Salted products
J 23(5): 775 (equilibrium moisture values of Atlantic cod)
S 990 (practical procedure for freshwater fishes)

Salts, metal (*see* names of elements; *also* Phosphates; Rancidity, oxidative)

Salvelinus alpinus (*see* Char, arctic)

Salvelinus fontinalis (*see* Trout, brook)

Salvelinus malma (*see* Dolly Varden)

Salvelinus namaycush (*see* Trout, lake)

Sampling; Sampling methods
J 23(7): 1083 (on deck from research vessel catches)
CNS 24 (B.C. commercial groundfish catches by areas, 1946–65)
S 1019 (random vs. stratified for Atlantic cod age & growth)

Sanddab, mottled (*Citharichthys sordidus*) (Pacific sanddab)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)

Sandeman, Edward John
S 1100 (redfish)

Sardine (Red Sea) (*Sardinella melanura*)
J 23(4): 601 (gamma irradiation as preservative)

Sardinella melanura (*see* Sardine (Red Sea))

Sardinops sagax (*see* Pilchard)

Saunders, John Wilfred
J 23(11): 1803 (estuarine spawning of Atlantic salmon)

Saunders, Richard Lee
J 23(10): 1617 (buoyancy in salmon)
S 999 (sublethal copper-zinc pollution in a salmon river)
1035 (West Greenland salmon fishery)
1082 (Greenland salmon fishery)

Saury, Atlantic (*Scomberesox saurus*)
B 154: 115 (as Nfld. resource)

Sausage, fish, and fish wiener
B 151: 19, 23, 36, 37 (equipment & recipe formulas for freshwater fishes)
CCG 7: 1 (bacterial counts re keepability, vs. meat sausage & wieners)

Saxidomus giganteus (*see* Clam, butter)

Scales
J 23(1): 149 (alkaline phosphatase in various fish)
(3): 459 (characteristics of Asian vs. Bristol Bay sockeye salmon)
(3): 463 (re Bay of Fundy capelin age)
(5): 747 (characteristics re pink salmon age determination)
(6): 939 (characteristics of B.C. pink salmon transplants to Nfld.)
(7): 1089 (portable press for making impressions)
(9): 1403 (times of annulus formation on Gulf of Alaska salmons)
(12): 1923 (bluegill sunfish, re growth characteristics)
S 1083 (for age, etc. of Atlantic salmon)

Scallop, giant (*Placopecten magellanicus*) (sea scallop)
B 154: 125 (as Nfld. resource)
S 1023, 1024 (ICNAF Canadian research reports)
1080 (fatty acids positional distribution in fat triglycerides)

Scallop, Iceland (*Chlamys islandicus*)
B 154: 125 (as Nfld. resource)

Scallop, sea (*see* Scallop, giant)

Schooling
J 23(2): 293 (factors affecting chum salmon fry)
(4): 547 (behaviour analysis procedure

Schwartz, Erich
J 23(9): 1331 (functions of lateral line)

Scomber scombrus (*see* Mackerel, Atlantic)

Scomberesox saurus (*see* Saury, Atlantic)

Scotian Shelf
J 23(8): 1145 (biology of Atlantic argentine)
S 1026 (1964 another cold sea temperature year)

Scott, Margaret Anne
J 23(7): 1025 (cod muscle lipids)
(10): 1629 (blood lipids of the lobster)

Scott, William Beverley
J 23(9): 1457 (longear sunfish in W. Ont.)
B 155 (fishes of Atl. coast)
CSG 47 (Canadian Atlantic sharks)
49 (pelagic fishes of the N.W. Atl.)

Sculpin, fourhorn (*Myoxocephalus quadricornis*)
S 1004 (re Canadian Arctic Islands marine-glacial relicts)

Sculpin, longhorn (*Myoxocephalus octodecemspinosus*)
J 23(3): 341 (swimming endurance re speed)
S 1087 (reaction to otter trawl, observed photographically)

Sculpin, mottled (*Cottus bairdi*)
J 23(5): 623 (association with brook trout in Pennsylvania streams)

Sculpin, slimy (*Cottus cognatus*)
J 23(5): 623 (association with brook trout in Pennsylvania streams)

Sea lettuce (*Ulva lactuca*)
S 1044 (thetin content as precursor of dimethyl sulphide odour in fish)

Sea lion, northern (*Eumetopias jubata*)
S 1046 (permanent canine teeth eruption)
1079 (faunal succession fom extinct forms)

Sea raven, Atlantic (*Hemitripterus americanus*)
J 23(3): 341 (swimming endurance re speed)

Sea stars (Starfishes)
J 23(11): 1673 (bathymetric distribution off Oregon coast)
B 152 (of arctic & subarctic N America)
S 1017 (of Labrador coast)
1108 (N American, from N Alaska to Strait of Belle Isle)

Sea water (*see also* Oceanography)
J 23(11): 1635 (chemical composition, bacteria & phytoplankton over P.E.I. oyster culture area)

Sea water, refrigerated (for holding fishery products)
J 23(6): 917 (effect of holding sockeye salmon on free oil of canned product)
S 1031 (containing added antibiotic)

Seal, Bearded (*Erignathus barbatus*)
B 154: 127 (as Nfld. resource)

Seal, gray (*Halichoerus grypus*)
B 154: 127 (as Nfld. resource)
S 972 (fatty acids types in blubber oil)

Seal, harbour (Atlantic) (*Phoca vitulina*)
B 154: 127 (as Nfld. resource)
S 1080 (fatty acids positional distribution in depot fat triglycerides)

Seal, harbour (eastern Pacific) (*Phoca vitulina richardi*)
J 23(4): 607 (foetal & postpartum whitecoat pelage)

Seal, harbour (western Pacific) (*Phoca vitulina largha*)
J 23(4): 607 (foetel & postpartum whitecoat pelage)

Seal, harp (*Pagophilus groenlandicus*)
J 23(5): 757 (reproductive rates)
B 154: 127 (as Nfld. resource)
S 1008 (exploitation & conservation)
1023, 1024 (ICNAF Canadian research reports)
1080 (fatty acids positional distribution in depot fat triglycerides)
1084 (netting & trapping on N shore of St. Lawrence R.)

Seal, hooded (*Cystophora cristata*)
B 154: 127 (as Nfld. resource)
S 1008 (exploitation & conservation)

Seal, ringed (*Phoca hispida*)
J 23(5): 769 (analysis of aerial census)
B 154: 127 (as Nfld. resource)
S 1004 (re Canadian Arctic Islands marine-glacial relicts)

Seals
S 1079 (faunal succession from extinct N. Pac. forms)

Seaperch, shiner (*Cymatogaster aggregata*)
S 1010 (*Parabomolochus*, copepod parasitic on gills)

Seaweeds (*see also* Dulse; Irish moss; Kelps; Sea lettuce)
B 154: 7, 144 (as Nfld. resources)

Sebastes marinus (*see* Redfish)

Sebastodes alutus (*see* Rockfish, longjaw)

Sebastodes caurinus (*see* Rockfish, copper)

Sebastodes elongatus (*see* Rockfish, greenstriped)

Sebastodes emphaeus (*see* Rockfish, PugetSound)

Sebastodes flavidus (*see* Rockfish, yellowtail)

Sebastodes jordani (*see* Rockfish, shortbelly)

Sebastodes paucispinis (*see* Bocaccio)

Sebastodes pinniger (*see* Rockfish, canary)

Sebastodes wilsoni (*see* Rockfish, pigmy)

Seiches
J 23(2): 278 (Long Point Bay, Lake Erie, Ont.)

Selectivity of fishing gear (see Trawl, otter)
J 23(2): 246, (3): 423 (gill & pound nets for lake whitefish)
S 1020 (otter-trawl re Atlantic cod girth–length relationships)

Semotilus atromaculatus (*see* Chub, creek)

Sergeant, David Ernest
J 23(5): 757 (reproductive rates of harp seals)
S 1008 (harp & hood seals)

Sergestes similis
J 23(8): 1135 (principal oceanic shrimp off Oregon coast)
(12): 1971 (feed & feeding apparatus)

Serum, blood
J 23(12): 1957 (proteins & antibody production in rainbow trout)

Seston
J 23(10): 1625 (efficiency of methods for determining)

Seymour, Allyn Henry
S 1061 (Alaska salmon resource)

Sex ratio
J 23(5): 623 (brook trout in infertile Pennsylvania streams)
(6): 797 (southern Nfld. herring population)
(7): 947 (salmon parr in Nabisipi R., Que.)

Shad, American (*Alosa sapidissima*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
S 1069 (two further records, Nfld.)

Shanny (*Leptoclinus maculatus*)
J 23(8): 1277 (first B.C. record)

Shark, blue (*Prionace glauca*)
CSG 47 (identification)

Shark, dusky (*Carcharhinus obscurus*)
CSG 47 (identification)

Shark, hammerhead (*see* Hammerhead)

Shark, sandbar (*Carcharhinus milberti*) (brown shark)
CSG 47 (identification)

Shark, sickle (*Carcharhinus falciformis*) (silky shark)
CSG 47 (identification)

Shark, whitetip (*Carcharhinus longimanus*)
CSG 47 (identification)

Sharks, Atlantic
CSG 47 (identification and other data, including tagging)

Sheepshead (*see* Drum, freshwater)

Shelbourn, John Edward
J 23(2): 293 (schooling of chum fry)

Shieh, Hang-shan
S 1042 (Betaine oxidation by *Achromobacter*)

Shellfish (*see* common names of species)

Shellfish occasional toxicity
J 23(8): 1265 (re Strait of Georgia *Gonyaulax acatenella* bloom)

Shiner, blackchin (*Notropis heterodon*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Shiner, golden (*Notemigonus crysoleucas*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Shiner, spottail (*Notropis hudsonius*)
J 23(1): 149 (alkaline phosphatase in scales)
(3): 455 (size re maturity)

Shooner, Gilles
J 23(7): 947 (Nabisipi R. salmon parr)

Shrimp, pink (*Pandalus borealis*)
B 154: 121 (as Nfld. resource)

Shrimp, striped pink (*Pandalus montagui*)
B 154: 122 (as Nfld. resource)

Shrimps, oceanic
J 23(8): 1135 (depth distribution off Oregon coast, U.S.A.)
(12): 1971 (feed & feeding apparatus of *Pasiphaea* & *Sergestes*)

Siliqua patula (*see* Clam, razor)

Silverside, brook (*Labidesthes sicculus*)
J 23(12): 1845 (mouth & body form re feeding ecology)

Sipos, John Charles
J 23(11): 1809 (fatty acid composition of cod lipids)
S 972 (isolation of saturated fatty acids of some marine lipids)

Sixteenmile Lake, B.C.
J 23(11): 1761 (life history & inlet stream spawning of longnose & white suckers)

Size (*see also* Length-frequency)
J 23(3): 455 (re maturity of spottail shiner)
(5): 729 (fishery effect on king crab populations structure)
(7): 947 (salmon parr in Nabisipi R., Que.)
(8): 1209 (re feed & growth efficiency of fishes)
B 152: 116 (& age at maturity)

Size limit (regulation)
J 23(4): 511 (Strait of Georgia lemon sole)
S 1039 (lobsters)

Skate (species ?)
S 1087 (behaviour toward otter trawl, observed photographically)

Skate, barndoor (*Raja laevis*)
B 154: 114 (as Nfld. resource)
S 1080 (fatty acids positional distribution in triglycerides)

Skate, smooth (*Raja senta*)
B 154: 115 (as Nfld. resource)

Skate, spinytail (*Raja spinacauda*)
B 154: 114 (as Nfld. resource)

Skate, thorny (*Raja radiata*)
J 23(4): 615 (new adrenal steroid from blood)
(10): 1587 (lipid oxidation test)

Skate, winter (*Raja ocellata*)
J 23(4): 615 (new adrenal steroid from blood)
B 154: 114 (as Nfld. resource)

Skates (Pacific)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)

Skeletonema costatum (diatom)
S 972 (fatty acids separation & types)
989 (growth-rate determination technique)

Skin
J 23(7): 1095 (pigments of coho salmon belly)

Skidmore, John Frederick
J 23(7): 1037 (zebrafish embryos)

Skipjack (*see* Tuna, skipjack)

Smelt, American (*Osmerus mordax*)
J 23(1): 149 (alkaline phosphatase from scales)

B 151 (freshwater: smoked; canned smoked; sausage)
154 (as Nfld. resource)
CCG 7: 27 (tank truck for chilling bulk quantities)
S 1098 (brief description; life history in Miramichi, R., N.B., and in Lake Ontario)

Smith, Howard D.
S 1061 (Alaska salmon resource)

Smith, Lynwood Stephen
J 23(9): 1439 (blood volumes of salmonids)
S 978 (dorsal aortic pressures in trout)

Smith, Michael
S 1041 (nucleotides in *Daphnia* embryos)

Smith, Morden Whitney
J 23(11): 1799 (organic matter lost by migrating eels)
S 1101 (Atlantic salmon)

Smoking; Smoked products (*see also* Delicatessen)
B 151: 5, 37 (equipment & recipe formulas, for freshwater fishes & fillets)
S 980 (brining & smokehouse data for freshwater fishes)
1081 (sweet-cured smoked sliced products from freshwater fishes)

Snailfish, slimy (*Liparis mucosus*)
J 23(2): 313 (first B.C. coastal record)

Snakes
S 1016 (of P.E.I.)

Snipe-eel, bobtail (*Cyema atrum*)
J 23(2): 305 (new NE Pac. Ocean record)

Snout (*see* Mouth)

Snow, Charles Dale
J 23(9): 1319 (mating behavior of crab)

Sole, arrowtooth (*see* Flounder, arrowtooth)

Sole, butter (*Isopsetta isolepis*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Sole, Dover (*Microstomus pacificus*)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Sole, English (*see* Sole, lemon (Pacific))

Sole, flathead (*Hippoglossoides elassodon*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial landings by areas, 1946–65)

Sole, lemon (Pacific) (*Parophrys vetulus*) (English sole)
J 23(4): 511 (appropriate size limits, Strait of Georgia)
(5): 701 (partial freezing for preservation)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B. C. commercial catches by areas, 1946–65)

Sole, petrale (*see* Brill (Pacific))

Sole, rex (*Glyptocephalus zachirus*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Sole, rock (*Lepidopsetta bilineata*)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
18 (length & age composition in Hecate Strait)
24 (sampling of B.C. commercial catches by areas, 1946–65)
S 1002 (virus tumors in skin of B.C.)

Sole, sand (*Psettichthys melanostictus*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)
S 1002 (virus tumors in skin of B.C.)

Sole, slender (*Lyopsetta exilis*)
CNS 24 (sampling of commercial B.C. catches by areas, 1946–65)

Sole, yellowfin (*Limanda aspera*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
24 (sampling of B.C. commercial catches by areas, 1946–65)

Sound
J 23(7): 1101 (production by American eel)

Sounding, echo
J 23(4): 499 (for yellow perch vertical distribution under ice)

Southcott, Burnett Anne
J 23(8): 1281 (thermal resistance of bacteria)

Sparks, Albert Kirk
J 23(12): 1913 (inflammation in the Pacific oyster)

Sparrow, Robert Arthur Hugh
J 23(12): 1875 (comparative limnology of lakes)

Spawning (*see also* Eggs, fish; Life history, etc.)
J 23(5): 651 (Nfld. & Grand Banks American plaice)
(8): 1145 (Atlantic argentine on Scotian Shelf)
(11): 1761 (inlet stream, of longnose & white suckers, B.C.)
(11): 1803 (estuarine, of Atlantic salmon in P.E.I.)
CNG 74 (1965 B.C. herring spawn deposition)

Spears, Doris Mae
J 23(9): 1325 (incidence of *Gaffkya homari*)

Speciation (*see* also Electrophoresis; Systematics; Taxonomy)
J 23(1): 101 (of *Oncorhynchus* & *Salmo* through muscle myogen & blood plasma protein electropherograms)
(1): 141 (*Coregonus autumnalis* & *C. laurettae*)

Species, new
J 23(6): 805 (*Bradyidius saanichi* calanoid copepod)
S 1002 (*Kofoidinium arcticum* dinoflagellate)

Species, new records or range extensions of
J 23(2): 305 (ogrefish & bobtail snipe-eel off Oregon & Washington)
(2): 309 (twoline eelpout, Greenland halibut & shortbelly rockfish off Vancouver Is. W coast)
(2): 313 (red gunnel & slimy snailfish off Vancouver Is. W coast)
(5): 715 (notch feelerfish on Grand Bank)
(6): 935 (spiny-cheek liparid off Oregon)
(8): 1161 (black ruff & Cornish blackfish in NW Atl.)
(8): 1257 (cranchiid squid from NW Atl.)
(8): 1277 (silver surfperch, brown Irish lord, shanny & kelp clingfish, from B.C. coast; review of 1961–66 other B.C. coast new records)
(9): 1455 (copper rockfish & green-striped rockfish Pac. range extension)
(9): 1469 (yellowtail rockfish, canary rockfish & bocaccio Pac. range extensions)
(12): 1967 (pigmy rockfish in B.C.)
S 1001 (B.C. Risso dolphin; feed, parasitization)
1067 (B.C. Polychaeta)

Species, origin of
J 23(1): 141 (arctic ciscoes)
(12): 1897 (palaeontology of some marine mammals)
S 1079 (faunal succession of N Pac. marine mammals)

Species, relict
S 1004 (Canadian Arctic Islands marine-glacial)

Speed, swimming (*see* Swimming)

Sphyrion lumpi (parasitic copepod)
J 23(4): 521 (reproduction in redfish)

Sphyrna lewini (*see* Hammerhead, scalloped)

Sphyrna zygaena (*see* Hammerhead, smooth)

Splake (hybrid from lake trout and brook trout)
J 23(1): 149 (alkaline phosphatase from scales)

Spleen
S 1073 (enzymes of Atlantic herring)

Spoilage (*see* Preservatives; Quality of fishery products)

Sport fishing (*see also* Salmon; Trout)
S 1015 (& facilities, Great Slave L.)

Sprague, John Booty
S 999 (sublethal copper-zinc pollution in a salmon river)

Spread, fish (*see* Delicatessen)

Squalus acanthias (*see* Dogfish, spiny)

Squalus suckleyi (*see* Dogfish, Pacific)

Squid (*Illex illecebrosus*)
B 154: 122 (as Nfld. resource)
CJG 13: 41 (life history; Nfld. abundance, catches, tagging)
S 972 (fatty acids types in liver oil)
1023 (ICNAF Canadian research report)

Squid, arctic (*Gonatus fabricii*)
CJG 13: 45 (strandings of young, Nfld.)

Squids
J 23(1): 85 (in feed of NE Pac. Ocean salmons & steelhead trout)
(8): 1257 (first NW Atl. record of *Pyrgopsis lemur*)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)
15, 20, 21, 22, 23 (in NE Pac. Ocean salmonid stomachs)

Squires, Hubert Jacob
J 23(4): 521 (reproduction in *Sphyrion lumpi*)
S 1107 (Crustacea distribution in NW Atl.)

St. Lawrence River
S 1084 (trapping & netting harp seals on N shore)

St. Lawrence, Gulf of
J 23(8): 1197 (sea floor conditions around Magdalen Is.)
(9): 1411 (electrical analog model for wind-driven circulation)
CSG 46 (changes in cod fishery)
S 1026 (1964 another cold sea temperature year)
1075 (evolution of cod fishery in southern part)

Staff, Fisheries Research Board of Canada
R 1964 (professional, by establishments in 1964; also index to)

Stannius, corpuscles of
J 23(8): 1249 (steroid transformations by, in Atlantic cod)

Starfish (*see* Sea stars)

Starvation effect (*see also* Feed; Hunger concept)
J 23(7): 975 (& refeeding, on Atlantic cod liver & blood constituents)
(9): 1353 (on chemical composition of early sea life pink salmon)
(9): 1461 (& severe exercise effects on rainbow trout glycogen metabolism)

Stations, Fisheries Research Board of Canada
R 1964 (locations; professional staffs; reviews of 1964 investigations)

Statistics (*see also* Mathematical treatment)
CJG 13 (1965 Nfld. flatfish & squid)
CNS 14, 19 (B.C. trawled groundfish landings, hours of effort & dispositions, 1964; 1965)
15 (stomach contents of 1958 catches of NE Pac. Ocean salmonids)
16, 27 (age & length composition of 1964 & 1965 B.C. sockeye, pink & chum salmon catches)
17 (length & age composition of petrale sole off Vancouver Is.)
18 (length & age composition of Hecate Strait rock sole)
20, 21, 22 23 (stomach contents of NE Pac. salmonid catches, 1956–57, 1959–60, 1962, 1963–64)
24 (inventory of 1946–65 samples of commercial B.C. groundfish landings)

Stenodus leucichthys (*see* Inconnu)

Sterilization (*see also* Irradiation)
J 23(8): 1281 (resistance of bacteria to, in fish spread delicatessen)

Steroids; Sterones (*see* Hormones)

Sterols (*see also* Hormones)
J 23(7): 1025 (cholesterol in fresh vs. frozen Atlantic cod muscle)
S 1071 (cholesterol glucopyranosiduronate synthesis)
1072 (cholesterol & related compounds in Irish moss)

Stevens, Ernest Donald
J 23(4): 471 (metabolism in trout)

Stewart, James Edward
J 23(1): 155 (fatty acids in cod livers)
(4): 595 (cultivation of oyster cells)
(9): 1325 (incidence of *Gaffkya homari*)
(9): 1451 (hemolymph of lobster)
S 1030 (anesthetics for lobster studies)

Stizostedion vitreum vitreum (*see* Walleye)

Stocks (*see also* names of organisms)
B 152 (B.C. petrale sole)
CSG 48 (further rehabilitation of Maritimes oyster)
S 973 (offshore NE Pac. Ocean coho salmon, & intermingling of E & W)
1025 (& recruitment, ICNAF area)

Stolzenberg, Ernest William
CNS 16 (age composition of B.C. salmon)
27 (age composition of B.C. salmon catches)

Stomach
J 23(9): 1353 (weight of pink salmon at various sea-life stages)
(10): 1607 (Atlantic cod morphology)

Stomach contents (*see also* Feed)
CNS 15, 20, 21, 22, 23 (salmonids in NE Pac. Ocean, 1956–64)

Strait of . . . (see name of strait)

Strickland, John Douglas Hipwell
B 122 (measuring marine phytoplankton production)

Sturgeon (Pacific)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)

Stutz, Sherwood Simpson
J 23(4): 607 (pelage in *Phoca vitulina*)

Succession of species (*see* Species, origin of)

Sucker, longnose (*Catostomus catostomus*)
J 23(1): 149 (alkaline phosphatase in scales)
(11): 1761 (life history & inlet stream spawning, Sixteenmile L., B.C.)
CCG 7: 16 (protein electropherogram)

Sucker, white (*Catostomus commersoni*)
J 23(1): 149 (alkaline phosphatase in scales)
(11): 1761 (life hitory & inlet stream spawning, Sixteenmile L., B.C.)

B 151 (canned; smoked; sausage; wiener; fishballs)
CCG 7: 16 (protein electropherograms)
S 1081 (sweet-cured smoked sliced products; recipes)

Sugars (*see also* Carbohydrates; Glycogen)
B 150: 21 (ribose & glucose re "greening" of tuna & albacore flesh)
S 1036 (phosphates of, in fish)

Sulphur compounds (*see also* Pollution; Thetin)
J 23(3): 357, (4): 487 (marine phytoplankton content of dimethyl sulphide precursor, re "blackberry" stomach of Atlantic cod)
CHN 25 (dimethyl sulphide re "blackberry" condition of Atlantic cod)
S 1034 (dimethyl sulphide re "blackberry" condition of Atlantic cod)
1041 (in algae)

Sunfish, bluegill (*see* Bluegill)

Sunfish, longear (*Lepomis megalotis*)
J 23(9): 1457 (northern range extension into W Ont.)

Superchilling (*see* Chilling; Freezing)

Superior, Lake (*see also* Great Lakes)
CCG 7: 21 (extension of sea lamprey control to lower lakes)

Surfperch, silver (*Hyperprosopon ellipticum*)
J 23(8): 1277 (first B.C. record)

Sutherland, Donald Bain
J 23(9): 1447 (holding tank for fish)

Sutherland, Kenneth
J 23(7): 1089 (salmon scales)

Suzuki, Beverly Miyuki
CNS 24 (market samples of B.C. groundfish landings)

Swimming
J 23(2): 181 (speed of spawning migratory sockeye & coho salmon)
(3): 341 (endurance of some NW Atl. Ocean fishes re temperature & swimming speed)
S 998 (energetics of sockeye salmon)

Swordfish (*Xiphias gladius*)
J 23(12): 1821 (nucleotide degradation of ordinary and red, re quality)
B 154: 97 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)
1099 (brief description; life history)

Systematics (*see also* Speciation; Taxonomy)
S 1037 (imperfections in international)

T

Tabata, Susumu
J 23(6): 825 Pac. oceanographic conditions)
S 977 (isothermal surface layer of water)
1033 (variability of oceanographic conditions)

Tagging methods, returns, losses, and interpretation (*see also* Marking)
J 23(2): 253 (losses: lake whitefish, Georgian Bay, Ont.)
(7): 947 (re juvenile Atlantic salmon in Nabisipi R., Que.)
B 153: 16 (B.C. petrale sole)
S 1038 (1964 INPFC Canadian high-seas research on salmons)

Tank (*see also* Aquaria)
CCG 7: 27 (truck for chilling freshwater smelt in bulk)

Tapeworms
CCG 7: 9 (re whitefish improvement through pike & *Triaenophorus* control; *Triaenophorus crassus* life history)

Tarr, Hugh Lewis Aubrey
J 23(3): 395 (nutritive value of fish meals)
S 1011 (phosphorylation in salmon milts)
1031 (preservation of fish by antibiotics)
1036 (phosphorus compounds in fish)

Taste panels (*see* Quality of fishery products)

Taxonomy (*see also* Speciation; Systematics)
J 23(5): 715 (*Bathypterois dubius*)

Taylor, Frank John Rupert
J 23(8): 1265 (*Gonyaulax acatenella*)

Teeth
S 1046 (eruption of northern sea lion permanent canine)
1078 (walrus age determination from)

Temperature, water (reactions to)
J 23(1): 1 (brook trout blood respiratory function)
(1): 15 (yellow perch total annual growth)
(1): 157 (downstream migrating brown trout)
(2): 293 (aggregations of chum salmon fry)
(3): 319 (Pacific cod embryonic development)
(3): 341 (swimming endurance of some NW Atl. fishes)
(6): 869, (8): 1209 (& feed effects on fish metabolism re body weight)
(8): 1109 (hematological responses of goldfish to sublethal cooling)
(8): 1121 (re oxygen in trouts embryo development)

(8): 1187, (10): 1581 (Atlantic salmon respiratory function)
S 983 (lethal heat shock effect on goldfish water balance)
1051, 1053, 1055, 1057, 1058 (haddock in Nfld. areas)
1052, 1053, 1055, 1059, 1060 (cod in Nfld. areas)
1053 (mass mortalities of various Nfld. area fishes due to low sea temperatures)

Temperature of natural waters (*see* Limnology; Oceanography; *also* names of lakes or other bodies of water)

Templeman, Wilfred
J 23(5): 715 (*Bathypterois dubius*)
(8): 1161 (family Centrolophidae)
B 140 (répartition des requins)
154 (marine resources of Nfld.)
S 1018 (ICNAF area conservation actions)
1023 (Atl. fisheries research; a review)
1025 (maximum yield of fishes)
1053 (mass mortality of fishes)
1054 (cod and haddock behaviour in Nfld. areas)
1055 (successful year-classes of cod haddock, and herring)
1056 (anomalies of sea temperature)
1057 (haddock distribution on Grand Bank)
1058 (haddock distribution on St. Pierre Bank)
1059 (cod catches in Hamilton Inlet Bank)
1060 (cod availability in St. Mary's Bay, Nfld.)
1089 (fisheries stituation in NW Atl.)

Tenebrio molitor (*see* Mealworm)

Theragra chalcogrammus (*see* Whiting (Pacific))

Thermal effects (*see also* Temperature)
J 23(8): 1281 (resistance of bacteria to heat processing fish spread)

Thermocline (*see also* Limnology; Oceanography)
S 1014 (possibility of estimating depth of oceanic, from satellite data)

Thetin (*see also* Sulphur compounds)
S 1009, 1044 (from algae as precursor of odd-number fatty acids in fish)

Thiamine (*see* Vitamin B group)

Thiobarbituric acid rancidity test
J 23(5): 737, (10): 1587 (effect of inorganic iron salts on)

Thomas, Martin Lewis Hall
S 981 (observations on the common limpet)
1016 (snake fauna of western P.E.I.)

Thomson, John Arthur
CNG 73 (groundfish fishing in Hecate Strait in 1965)
CNS 14 (B.C. landings of trawl-caught groundfish)
19 B.C. landings of trawl-caught groundfish)

Thunnus alalunga (*see* Albacore)

Thunnus thynnus (*see* Tuna, bluefin)

Thymallus arcticus (*see* Grayling, arctic)

Tibbles, John James
CCG 7 (sea lamprey control in lower Great Lakes)

Tibbo, Simeon Noel
J 23(3): 463 (capelin in Bay of Fundy)
CSG 47 (Canadian Atlantic sharks)
49 (pelagic fishes of the NW Atl.)
S 1099 (swordfish)
1103 (Atlantic herring)
1104 (Atlantic mackerel)

Tides; Tidal effects
S 979 (flushing rates re pulpmill effluent into channels near Nanaimo, B.C.)

Tilapia (*Tilapia mosambica*)
J 23(1): 149 (alkaline phosphatase in scales)

Tilapia mosambica (*see* Tilapia)

Tocher, Carol Ann Shipton
J 23(3): 357 (dimethyl-β-propiothetin)
S 1044 (dimethyl-β-propiothetin in algae)

Tolerance (see Oxygen, dissolved; Pollution; Salinity (reactions to); Temperature, water (reactions to); Toxicants)

Tomlinson, Neil
J 23(5): 673 (chalkiness in halibut)
(5): 701 (fish preservation by partial freezing)
(6): 917 (salmon oil binding
(6): 925 (chalkiness in halibut)
B 150 (greening in tuna)

Tooth (*see* Teeth)

Topminnow, blackstripe (*Fundulus notatus*)
J 23(9): 1331 (surface waves perception by lateral line organs)

Toxaphene (*see* Toxicants for fishes)

Toxicants for fishes
J 23(5): 723 (bioassay method for toxaphene in lake waters)

Toxicity (*see* Pollution; Shellfish occasional toxicity; Toxicants for fishes)

Trachurus symmetricus (*see* Mackereljack)

Transplantation
J 23(6): 939 (pink salmon from B.C. to Nfld.: scale characters)
CSG 48 (Maritimes oyster spat)
S 1007, 1085, 1105 (pink salmon from B.C. to Nfld.: spawning returns)
1096 (lobsters to B.C.)

Transport, mass (of waters)
J 23(6): 852 (NE Pac. Ocean)

Traps; Trapping
S 1039 (lobster: legal lath spacing)
1084 (harp seals on N shore of St. Lawrence R.)

Trawl, otter
J 23(1): 153 (underwater observation of fish behaviour towards)
(4): 611 (design of side-trawling type)
(10): 1507 (causing haddock mortality from fatigue)
CNG 73: 1 (for Hecate Strait groundfish exploration)
S 1020 (selectivity re Atlantic cod girth–length relations)
1087 (reaction of Atlantic fish to, observed photographically)

Trawling (*see also* Flatfishes; Groundfish)
S 1076 (1965 offshore lobster investigations, Canadian & American)

Trematoda (*see* Flukes)

Tresus capax (*see* Clam, horse)

Triaenophorus species (*see* Tapeworms)

Triglycerides (*see also* Acids, fatty; Lipids; Oils and fats)
S 985, 1028 (fatty acids positional distribution in fat triglycerides of various organisms)
1029 (fatty acids positional distribution in fat triglycerides of various vegetables)
1047 (unsolved analysis problem)
1065 (fatty acids distribution determination by Grignard reagent deacylation)

Trimethylamine; Trimethylamine oxide
B 150: 18 (re "greening" of tuna & albacore flesh)

Trout, alpine (*see* Char, arctic)

Trout, brook (*Salvelinus fontinalis*) (speckled trout)
J 23(1): 1 (blood respiratory function after seasonal temperature acclimation)
(5): 623 (maturation & fecundity in infertile Pennsylvania streams)
(7): 1007 (responses of young to light)
(8): 1121 (oxygen re temperature in embryo development)
(10): 1537 (development rate & vertebral number)
(10): 1599 (electropherograms of myogen & hemoglobin)
(11): 1799 (production in Crecy L., NB.,as affected by eels)
(12): 1977 (distribution in association with young Atlantic salmon)
B 154: 103 (as Nfld. resource)
S 1007, 1085 (reports on investigation & management in Maritimes)
1028, 1080 (fatty acids positional distribution in fat triglycerides)

Trout, brown (*Salmo trutta*)
J 23(1): 157 (downstream migration re temperature & light)
(5): 623 (association with brook trout in Pennsylvania streams)
B 154: 103 (as Nfld. resource)

Trout, cutthroat (*Salmo clarki*)
J 23(10): 1475 (open-water movements in Yellowstone L.)

Trout, hybrid (*see* Splake)

Trout, lake (*Salvelinus namaycush*) (*Cristovomer namaycush*)
J 23(10): 1599 (electropherograms of muscle myogen & hemoglobin)
B 151 (canned; smoked)
CCG 7: 16 (protein electropherogram)
7: 33 (freezing rate; latent heat of freezing)
S 980 (brining time before smoking)
1015 (Great Slave L. sport fishery)

Trout, rainbow (*Salmo gairdneri*)
J 23(1): 65, (4): 471, (6): 783, (9): 1461 (effect of physical conditioning on metabolism)
(2): 207, (11): 1811 (muscle lecithinase activity, distribution)
(4): 563 (myosin preparation & properties)
(6): 929 (electropherograms of multiple hemoglobins)
(7): 983 (light intensity re seeking overhead cover)
(8): 1121 (oxygen re temperature in embryo development)
(9): 1439 (blood volume determination)
(10): 1487 (response to bacterial antigens)
(10): 1537 (development rate & vertebral number)
(12): 1957 (serum proteins and antibody production)
B 154: 103 (as Nfld. resource)
S 978 (dorsal aortic blood pressures)

Trout, speckled (*see* Trout, brook)

Trout, steelhead (*Salmo gairdneri*) (steelhead salmon)
J 23(1): 85 (stomach contents in NE Pac. Ocean)
(1): 101 (biochemical evidence re interspecies relationships with *Oncorhynchus*)
(3): 365 (life history characteristics variability)
(9): 1439 (blood volume determination)
CNS 15, 20, 21, 22, 23 (stomach contents, NE Pac. Ocean, 1956–64)
S 1011, 1036 (milt enzyme for nucleoside phosphate synthesis)

Trout, yellowstone cutthroat (*Salmo clarki clarki*)
J 23(6): 929 (electropherograms of multiple hemoglobins)
(10): 1475 (open-water movements)

Truscott, Beryl
J 23(4): 615 (1α-hydroxycorticosterone)

Tsuyuki, Hiroshi
J 23(1): 101 (*Oncorhynchus* muscle myogens)
(6): 929 (micro starch gel electrophoresis)
(10): 1599 (muscle myogen patterns)
(11): 1663 (comparative electropherograms)

Tucker, Harold Herbert
J 23(1): 1 (blood of brook trout)
(8): 1187 (oxygen dissociation curves)
(10): 1575 (effect of hemolysis)
(10): 1581 (oxygen dissociation curves)

Tullibee (*Coregonus*)
CCG 7: 33 (latent heat of freezing)
S 980 (brining time before smoking)

Tully, John Patrick
S 1014 (estimating depth of the thermocline)
1032 (time series in oceanography)

Tumor (*see* Disease)

Tuna, bluefin (*Thunnus thynnus*)
B 154: 95 (as Nfld. resource)
S 1024 (ICNAF Canadian research report)

Tuna, skipjack (*Euthynnus pelamis*) (skipjack)
S 1024 (ICNAF Canadian research report)

Tunas (*see also* Albacore)
B 150 ("greening" of flesh during precooking before canning)

Turbidity
J 23(2): 281 (Long Point Bay, Lake Erie, Ont.)

Turbot (*see* Flounder, arrowtooth; Halibut, Greenland)

Turkey
S 1028, 1080 (fatty acids positional distribution in pygostyle fat triglycerides)

Tusks
S 1078 (walrus age determination from)

U

Ulva lactuca (*see* Sea lettuce)

Umbra limi (*see* Minnow, mud)

Urophycis tenuis (*see* Hake, white)

Uthe, John Frederick
J 23(10): 1599 (muscle myogen patterns)
(11): 1663 (comparative electropherograms)
CCG 7 (method of identifying species of fish)

Uyeno, Fukuzo
J 23(11): 1635 (nutrients in an estuarine area)

V

Van Cleve, Richard
J 23(11): 1789 (obituary — W.F. Thompson)

Vanstone, William Edward
J 23(7): 1095 (pigment in salmon skin)
(9): 1353 (composition of young pink salmon)

Vegetables
S 1029 (fatty acids positional distribution in fat triglycerides of various)
1074 (rapeseed oil monoethylenic fatty acids)

Venerupis japonica (*see* Clam, Manila)

Vertebrae
J 23(10): 1537 (number re salmonids development rate)
(11): 1815 (number in yellow perch re lakes salinity)

Vervoort, W.
S 1010 (rediscovery of *Parabomolochus cuneatus* (Fraser))

Vessels, research
J 23(4): 611 (design of side-trawling gear for *G.B. Reed*)
(7): 1083 (deck sampling of catches)

S 1086 (research vessel *E.E. Prince* launched)

Virus (*see* Disease)

Vitamin B group
J 23(6): 915 (in dulse algae)
S 996 (synthesis of coenzyme B_{12} analogs)

Volume
J 23(8): 1285 (of various phytoplankton species)
(9): 1439 (determination of salmonids blood)

Vosella modiolus (*see* Mussel, horse)

W

Waldichuk, Michael
S 979 (estimation of flushing rates from tide height)
1066 (sulfite wastes)

Walleye (*Stizostedion vitreum vitreum*) (yellow pike; yellow pickerel)
J 23(1): 149 (alkaline phosphatase in scales)
(6): 941 (feeding re introduced smallmouth bass in a Man. lake)
(11): 1663 (muscle myogens & blood hemoglobin electropherograms)
B 151 (smoked)
CCG 7: 16 (protein electropherogram)
7: 33 (latent heat of freezing)
S 980 (brining time before smoking)
1015 (Great Slave L. sport fishing)

Walrus
S 1078 (biology & economics in Canadian arctic)
1079 (faunal succession from extinct N Pac. forms)

Water balance
S 983 (lethal heat shock effect on goldfish)

Water content (*see* Moisture content)

Waters, natural (*see also* Limnology, Oceanography)
J 23(2): 275 (Inner Long Point Bay, Lake Erie, Ont.)
(4): 575 (distribution & speciation in Fraser R. & adjacent marine)
(5): 723 (bioassay method for toxaphene in lake waters)
(12): 1875 (chemical constituents of 9 B.C. Rocky Mt. Trench lakes)
S 1004 (analyses, of 6 Canadian arctic lakes)

Watt, Alexander
S 1040 (algae enolase)

Waves
J 23(9): 1331 (perception mechanism of topminnow, for surface ripples)

Wawreszuk, Helena
J 23(11): 1653 (chemical composition of crayfish)

Webb, Deirdre
J 23(12): 1845 (mouth & body form in fish)

Weight (*see also* Length–weight ratio)
J 23(6): 869, (8): 1209 (re metabolism of fishes: effect of feed & water temperature)
(8): 1285 (dry, of various planktonic algae)
(9): 1353 (body, of pink salmon at various sea-life stages)
CHN 27 (gain & loss of fillets during processing & storage)
S 1027 (changes in Atlantic herring frozen vs. stored in formalin)

Weinstein, Harvey Marvin
S 1043 (glycolytic metabolites in cod muscle)

Wells, Richard
S 1052 (cod growth & temperature in Nfld. area)

Westrheim, Sigurd Jergen
J 23(2): 309 (new B.C. fishes)
(4): 611 (groundfish trawl net)
(9): 1455 (W Pac. range extension for two rockfish species)
(9): 1469 (northern range of rockfish)

Whale, blue (*Balaenoptera musculus*)
B 154: 138 (as Nfld. resource)

Whale, fin (*Balaenoptera physalus*) (finback whale)
B 154: 138 (as Nfld. resource)
S 927, 975, 976 (fatty acids types in blubber oils, & possible physiological function of blubber)

Whale, humpback (*Megaptera novaenangliae*)
B 154: 138 (as Nfld. resource)

Whale, killer (*Grampus orca*)
B 154: 144 (as Nfld. resource)

Whale, minke (*Balaenoptera acutorostrata*)
B 154: 144 (as Nfld. resource)

Whale, pilot (*Globicephala melaena*) (pothead whale)
B 154: 141 (as Nfld. resource)
S 1080 (fatty acids positional distribution in depot fat triglycerides)

Whale, pothead (*see* Whale, pilot)

Whale, right (*Evbalaena glacialis*)
B 154: 138 (as Nfld. resource)

Whale, sei (*Balaenoptera borealis*)
B 154: 138 (as Nfld. resource)

Whale, sperm (*Physeter catodon*)
S 1079 (faunal succession from extinct form)

Whales
S 1079 (faunal succession of N Pac.)

Whitefish, lake (*Coregonus clupeaformis*)
J 23(1): 149 (alkaline phosphatase in scales)
(2): 221 (dynamics & exploitation, Georgian Bay, Ont.)
(3): 423 (selectivity of gillnets for)
(6): 929, (10): 1599 (electropherogram of multiple hemoglobins)
B 151 (canned; smoked; sausage; wiener; fishballs)
CCG 7: 1 (keepability of sausage & wiener)
7: 9 (improvement by pike & *Triaenophorus* control)
7: 16 (protein electropherogram)
7: 33 (freezing rate; latent heat of freezing)
S 980 (brining time before smoking)

Whitefish, mountain (*Prosopium williamsoni*)
J 23(1): 45 (hematological study)

Whitefish, round (*Prosopium cylindraceum*)
J 23(1): 149 (alkaline phosphatase in scales)

Whiting (Pacific) (*Theragra chalcogrammus*) (walleye pollock; bigeye)
CNG 73 (in Hecate Strait exploratory fishing)
CNS 14, 19 (B.C. landings by areas, 1964, 1965)

Wieners, fish (*see* Sausage, fish)

Wilder, Donald George
CSG 50 (Canadian Atlantic crab resources)
S 1039 (lobster conservation in Canada)
1106 (American lobster)

Williams, Peter Montague
J 23(4): 575 (iron in natural waters)

Wilson, Geoffrey Gordon
J 23(6): 813 (toxicity of kraft mill wastes)

Wind; Wind effects
J 23(6): 850 (NE Pac. Ocean)
(9): 1411 (on Gulf of St. Lawrence currents: electrical analog model for)
S 977 (speed re NE Pac. Ocean summer isothermal surface layer)

Windermere, Lake (England)
J 23(10): 1495, 1523 (pike feed consumption studies)

Witch (*see* Flounder, witch)

Withler, Ira Louis
J 23(3): 365 (characteristics of steelhead trout)

Wolffish, Atlantic (*Anarhichas lupus*) (sea catfish)
J 23(10): 1587 (lipid oxidation test)
B 154: 111, 154 (as Nfld. resource)

Wolffish, northern (*Anarhichas denticulatus*)
B 154: 111, 154 (as Nfld. resource)

Wolffish, spotted (*Anarhichas minor*)
B 154: 111, 154 (as Nfld. resource)

Wolmark, Norman
S 1028 (fatty acid distribution in triglycerides)

Woo, Patrick T.K.
J 23(12): 1965 (records of *Cryptobia salmositica* from sockeye salmon)

Wood, Alec James
CHN 24 (freeze-drying of Atl. fishes)

Woodey, James Carter
J 23(12): 1965 (records of *Cryptobia salmositica* from sockeye salmon)

Woodland, Bruce
S 1086 (research vessel *E.E. Prince*)
1096 (B.C. lobster transplant)
1102 (Greenland salmon fishery)

Wydoski, Richard Stanley
J 23(5): 623 (fecundity of brook trout)

X

X-Ray
J 23(12): 1969 (northern pike accessory fin)

Xanthochroism
J 23(12): 1981 (of bocaccio colour variant)

Xiphias gladius (*see* Swordfish)

Y

Yellowtail (*see* Flounder, yellowtail)

Yield
J 23(2): 263 (re lack whitefish standing crop)
(4): 511 (re Strait of Georgia lemon sole size limit)
S 1025 (maximum sustained: lack of research data for calculations re ICNAF area)

Yurkowski, Michael
S 986 (preparation of L-α-glyceryl phosphoryl choline)
1029 (stereospecific analyses of vegetable fats)

Z

Zebrafish (*Brachydanio rerio*)
J 23(7): 1037 (resistance of immature embryos to zinc sulphate)

Zinc compounds
J 23(7): 1037 (resistance of immature zebrafish embryos to sulphate)
S 999 (sublethal Cu-Zn pollution re young salmon & insect larvae)

Zooplankton (*see also* Feed; Plankton)
J 23(1): 85 (in feed of NE Pac. Ocean salmons & steelhead trout)
(2): 189, (3): 415 (free-swimming copepod nauplii)
S 1013 (Lake Hazen, N.W.T.)